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DYNAMO-ELECTRIC MACHINERY.

By PROF. GEORGE FORBES, M.A., F.R.S.E.

[A Lecture delivered at the INTERNATIONAL ELECTRICAL EXHIBITION of the FRANKLIN INSTITUTE, Tuesday, September 16, 1884.]

Mr. W. P. TATHAM, president of the Franklin Institute, introduced the lecturer, and spoke as follows:

LADIES AND GENTLEMEN:—It has been the earnest desire of the managers of the Franklin Institute, and particularly of Col. Banes, the chairman of the committee in charge, to give the present exhibition an educational character; and to this object they have arranged a series of lectures to be delivered in this hall on Tuesday and Thursday of each week. The present lecture will be on the subject of "Dynamo-Electric Machinery," and will be delivered by Prof. George Forbes, of London, whom I now have the honor of presenting to you.

PROFESSOR FORBES spoke as follows:

LADIES AND GENTLEMEN:—The subject of this evening's lecture is Dynamo-Electric Machinery, and it ought, perhaps, in greater strictness to be defined as dynamo-electric machinery in general, and not dynamo-electric machinery in particular; because in a single lecture it is impossible to go into the whole subject of the differences between various types of machines, and all I can hope to do in the course of this lecture is to give to you a general insight into the theory and principles of construction of dynamo machinery and of the progress

which has been made up to the present time in theoretical investigation and practical application.

At the beginning of this century our information about the action of electrical currents was extremely limited indeed, and it was not until a great discovery was made in the year 1820 that the basis was laid for those developments which have culminated in the vast number of machines which you see around you in this exhibition. At the commencement of the century, in fact up to quite a recent date, the current of electricity was developed, not by means of these machines which we see around us in the exhibition, but by means of a chemical apparatus which was called a voltaic battery, such a one as I hold in my hand here, which consists of two dissimilar metals, one of which is zinc and the other may be of carbon, copper or some other metal. When these two metals are dipped into a suitable acid and connected by a wire, a current of electricity is said to pass from the copper through that wire to the zinc. Now, if you ask me what is the current of electricity, I am bound to confess to you that I do not know. All that I can do is to give you some analogy to fix your mind upon while you are thinking about a current of electricity. If I were to take a copper wire and hold one end of it in a hot flame and hold the other end in a block of ice, heat would be absorbed in the end which was in the flame and heat would be given out in the end which was in the ice, and heat would be conducted along the wire. No material substance is conducted along that wire, and I am sure there are very few of you that can form any conception of what is passing along in the wire. But you have a notion, not a physical conception, of heat, and the phenomenon of heat transference through the wire is not unfamiliar to you. I do not say that electricity is the same as this, but it is the general opinion of scientific men that electricity passes through the wire in a somewhat similar manner to heat. It is energy and not matter which passes through the wire. That is not a tangible analogy.

I will try now to give you a clearer but grosser analogy. I allude to the analogy which exists between electricity and the flow of water in pipes. When we have a certain head or pressure of water we have also a flow of water through the pipes, and the greater the head or pressure the greater is the flow of water through the pipes. At the same time we have in the pipes a certain resistance to this flow, a resistance due to the small diameter of the pipe, and the smaller the

diameter the greater the resistance to the flow of water. In all these points electricity has an analogue. We are able to get up what we call an electric pressure or electro-motive force which exactly corresponds to the pressure of the head of water. When we have this electro-motive force in the wire, we are able to get a current of electricity through the wire. That is to say, a flow of electricity which is exactly analogous to the flow of water in the pipes. But this wire offers a resistance to the passage of electricity just as the pipe offered a resistance to the flow of water, and the larger the wire is, and the greater its sectional area, the greater is the flow of electricity, just as the greater the diameter of the pipe, the greater is the flow of water. Thus, I think you will admit that we have here a tangible analogy between the flow of water and the flow of electricity; and when I speak of the electro-motive force which we have, you will understand that it is

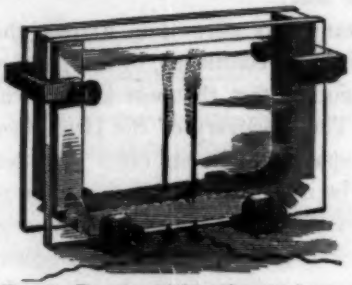

FIG. 1.—Decomposition of water by an electric current. (Cell upright.)

analogous to the pressure of water, and when I speak of the resistance it is analogous to the frictional resistance to the flow of water in the pipe.

Previous to the year 1820 the important facts which were known in connection with the electric currents were these: First, that if two wires coming from a voltaic battery were dipped into a solution of acidulated water, the elements of which the water is composed were separated or decomposed and rose as bubbles to the surface. This experiment I can show to you now by means of the magic lantern. We will lower the lights. We have now a cell which is exhibited on an enormous scale on this screen in an inverted position. (See Fig. 1.) Here is the top, and this is all air below; the cell being inverted the water which is contained in the cell is shown at the top of the picture; and here we have two wires; one is connected with the positive pole of the

voltaic battery and the other with the negative pole. If now the wires be connected we shall see bubbles of gas, hydrogen and oxygen, rising to the surface. This shows a decomposition of the water in the cell in a manner such as it would be impossible for me to show to you on the lecture table.

Another fact which was known at the same time and which was one of the few important facts known was this: that if a conductor, made thin enough, were brought in connection with the two poles of the battery it would become red hot or white hot.

I have underneath this table a voltaic battery connected with two wires coming above the table. You will be able to see as soon as I connect them with a thin piece of platinum wire that the wire becomes red hot, and if I diminish the resistance in the circuit by shortening the wire I can make it even hotter than that; I am able to make this wire of a bright red heat.

These two important facts were then known, the decomposition of water, and the heating of a conductor, by the passage of an electric current. There was another fact that was known which I ought not to omit to mention. The discovery of Sir Humphrey Davy, about the year 1811, that the spark which had often been seen on the breaking of the circuit could be intensified by using a large number of cells in a voltaic battery and taking the two ends of the wire and attaching to them two pieces of charcoal; on separating these two pieces of charcoal a brilliant light was seen to pass from one piece of the charcoal to the other. That is the fundamental experiment which led to the discovery of the electric light, that is the arc light, which is so very much used in this country.

I have in the course of the last few years visited each one of the different electrical exhibitions which have been held in Europe. Last year I was at one held in Vienna. After I had wandered about the exhibition and visited the host of applications of electricity rivalling in number those which you see in this Franklin Institute exhibition, the great variety of telegraph instruments, the hosts of different kinds of telephones and the great number of types of dynamos distributed all over the building, I happened to find myself standing in front of a small exhibit which filled me with respect and a feeling akin to awe. This was a small object placed upon velvet and covered with a glass shade, and behind it there was a bust of the illustrious man who had used this apparatus. I looked upon this instrument with respect,

because in the discovery made with it I saw the commencement and the dawn of the whole of that science of electricity which had reached such a culmination in the Vienna exhibition. I saw in that one experiment of that famous man the genesis of every one of the telegraph instruments in the exhibition, of every one of those telephones, of all the various applications of electricity, of every one of the types of dynamos in that building. I need hardly say to those acquainted with the history of electricity that I was looking at a small compass needle, and that the bust was that of the late Professor Oersted, of Copenhagen.

For many years people were aware that there was some hidden connection between the compass and electricity, between the power that impelled the compass to point to the north and the lightning in the sky. It had been believed that when lightning had disarranged the

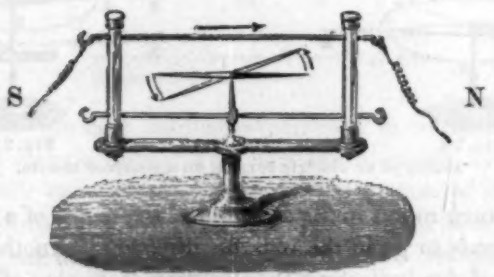

FIG. 2.—Action of an electric current on a compass needle.

compass needle and reversed its polarity it showed that there was some connection between electricity and magnetism, but no one could tell what that connection was. Mathematics were of no avail in the solution of this problem. Oersted happened to be experimenting with a battery and a compass and found the secret of the mystery, and it is from this point that we have to investigate the progress of electricity this evening.

Here we have a compass needle suspended under a wire. (See Fig. 2.) The wire will presently have an electric current passing through it. Oersted found that when the current coming from the copper pole passed over a compass needle from the south to the north, the compass needle moved with its north pole towards the west. That is, the compass needle was moved by the influence of the electric current, an action taking place between the current over it and itself. On this compass

needle I have put some pieces of paper that you may be better able to see the experiment. If Mr. Knapp, who is kindly giving me his assistance, will now lower the plates into the battery you will immediately see a declination of the north pole of the compass to the west. On breaking the current the compass needle, as you see, immediately resumes its position from north to south. In other words, when the current is flowing in this direction the north pole of the compass needle goes to your left. That is to say, if I be looking in the direction in which the current is going, the north pole of the compass needle seems to go round the wire in the direction of the hands of a watch. And if I had the compass needle at one side of the current the north pole would

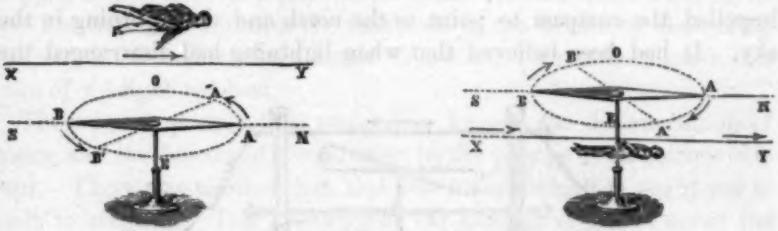

FIG. 2 *a*. FIG. 2 *b*.

Action of an electric current on a compass needle.

still tend to turn round in the direction of the hands of a watch. The south pole tends to go in the opposite direction. Another means has been proposed for indicating the direction of motion of the compass needle. If a man be supposed to be swimming in the direction of the current and facing the compass needle, he will see the north pole going to the left. In this way, looking at Fig. 2 (*a*) and Fig. 2 (*b*), we see that a current going from south to north, if above the compass, deflects it to the west of north, and if below, to the east of north. There are various results which we can see to follow from this principle. Here I have a rough ring to illustrate the direction in which the current is going. (See Fig. 3.) Let the light arrows show the direction of the current. Now, I have found, when I am looking along these the north point appears to go round in the direction of the hands of a watch; so, also, looking at it from another point, the needle would still tend to go round in the direction of the hands of the watch, so that wherever in front of this circle I may hold the north pole of the compass needle it will always tend to go through the circle in that direction if the current is going in the direction of the arrows. Here, we have a method of

intensifying what was shown by Oersted. If I hold a compass in front of a coil the north pole will tend to be sucked in, in that direction; and the south pole would be sucked in, in a similar manner if held at the other side of the coil.

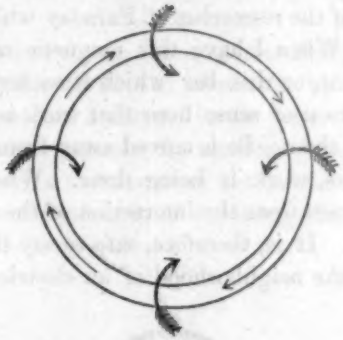

FIG. 3.—A current passing in direction of light arrows moves a north pole in direction of dark arrows.

I will show you next another experiment to illustrate the analogy between the electric current and magnetism, which follows directly from Oersted's experiments. Here I have a mass of iron or sets of bars going directly downwards with iron at their base and coils of copper wire surrounding them through which I can pass an electric current. As soon as I pass such a current through the wire this becomes a powerful magnet capable of attracting iron objects placed in its neighborhood. It will hold a bar of iron like this with enormous intensity. So, if I tumble upon the poles a quantity of nails the magnetic attraction is so great as to give the nails the appearance of cohesion which enables them to stand upright in a bridge; but as soon as I take away the current they fall down, which shows that the magnetism has left the magnet as soon as the current ceases to flow. (See Fig. 4.) In this experiment the north polarity is urged through the iron in the direction indicated by Oersted's experiment.

Having shown you how a magnet can be produced, I will show you the experiment which I described just now. Here I have a coil of wire analogous to the coil which Mr. Knapp was just now holding in his hand, and here I have a bar of iron, and I have said that if I have a north pole under here it will be sucked up if the current is going in the right direction. Now the coil will magnetize this bar. As soon

as I have magnetized the bar it has a north pole at the top, which is powerfully sucked in. The intensity of the magnetic effect of this current of electricity is so great that I have considerable difficulty in dealing with this mass of iron which I am holding in my hand.

Now, in this experiment I wish to point out to you the key that exists to the whole of the researches of Faraday which were made some years afterwards. When I have this magnetic needle, which is deflected by the current, or this bar which is sucked into the coil, it is evident to every person of sense here that work is being done. That is to say, that when the needle is moved away from the position which it naturally occupies, work is being done. Where does this work come from? It comes from the interaction of the compass needle and the electric current. It is, therefore, safe to say that when a compass needle is moved in the neighborhood of an electric current it is doing

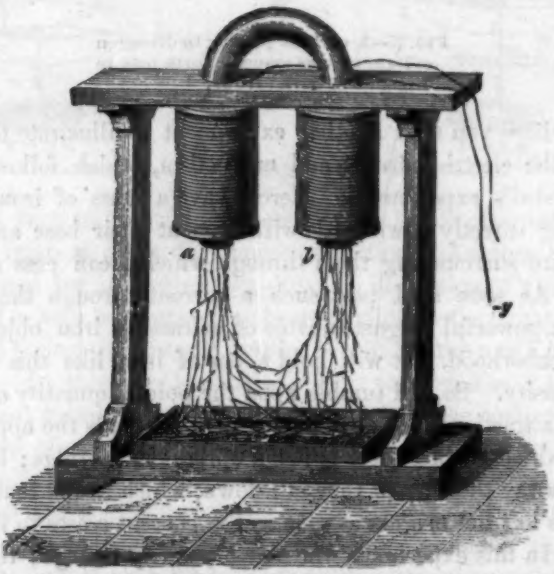

FIG. 4.—Electro-magnet supporting a bridge of nails.

work, and in order to do work it must take away a part of the current from that current which is acting. Now, in order to take away from the current it must have started a feeble opposing current in an opposite direction. And here is the point that I wish you to grasp, that in the movement of the compass needle from one side or the other, an

opposing electro-motive force has been created, that is, a force tending to set up a current in the wire in the opposite direction. This I believe was the manner in which Faraday argued the matter out in his mind and that is how he was able to originate the experiments which he made to produce the opposite result, that is, to create a current in the wire.

Hitherto, Oersted had shown that a current could produce motion in a magnet; Faraday conceived the idea that by the motion of the magnet we could produce a current in the wire. This experiment I shall now be able to show you. By moving a magnet pole into a coil you will be able to see a movement of the pointer which I have here and which indicates the strength of currents which are made to flow

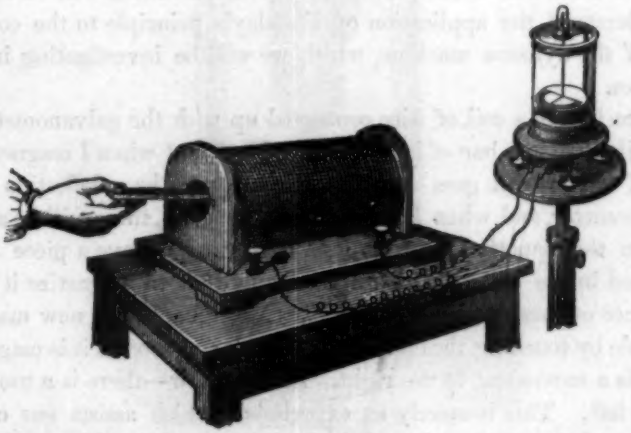

FIG. 5.—Galvanometer showing an induced current while a magnet is moving into a coil of wire.

through wires which are connected with it. This instrument which I have here is a galvanometer, an instrument whose object is to measure the strength of electric currents. You see the index traveling over the scale at the present moment; it now points almost to the middle of the scale. If then, I take an ordinary coil of wire and reverse the experiment which I was talking of a short time ago, that is to say, pass the pole of the magnet into the coil of wire, we shall find that the electro-motive force is started in the coil of wire, and if the circuit of the wire forming the coil be completed through the galvanometer, we shall find that a current is created which will show itself by the deflection of the galvanometer. (See Fig. 5.) Now, in order that this be made distinct,

I shall ask Mr. Knapp suddenly to insert the north pole of the magnet into the coil of wire. The movement of the galvanometer will be very slight, but you will be able to see it. I will now ask him to withdraw the pole and the movement will be in the opposite direction. In this manner I get up a sort of swing in the galvanometer which is more visible to you and shows that I can move the galvanometer needle from one side to the other when I put in the north pole of the compass or draw it out. The motion you see is very slight, but I am perfectly able to control it; it moves always to the right when I put the pole in and always to the left when I take the pole out. This movement of the index proves that Faraday's notion was right.

I am anxious now to show you this experiment in another way, for it shows a further development of our notion which will enable you to understand the application of Faraday's principle to the construction of the dynamo machine, which we will be investigating in a few minutes.

Here I have a coil of wire connected up with the galvanometer. In the coil there is a bar of iron. I show you that when I magnetize the bar of iron which goes through it, there will be a deflection of the galvanometer, and when I reverse the magnetism, there will be a deflection in the opposite direction; so that when I have a piece of iron enclosed in the coil of wire all I have to do is to magnetize it by the influence of these neighboring poles. Mr. Knapp will now magnetize the pole by touching the end with a magnet; as soon as it is magnetized there is a movement to the right. Reverse now—there is a movement to the left. This is merely an experiment which assists our comprehension of the construction of the machine, or shows that magnetizing the iron core produces the same effect as the introduction of the magnetic pole into the system.

Now let us see how all these principles, discovered by Faraday, can be applied to the construction of dynamo-electrical machines. You have seen when I have a coil here with the north pole introduced through it that there is then a current of electricity established in it, and that current is established only while the north pole is passing through it. When the magnet is fixed no action is taking place. I have introduced the north pole into the coil and if I withdraw that north pole by the way it went in, I shall of course create a current in the opposite direction. If, on the other hand, I carry the south pole in the same direction in which the north pole has gone, it also will create

a current in the opposite direction. After I have passed the north pole through the coil, it is impossible to increase the current in that direction. The further motion of the other pole must produce a current in the opposite direction to the current first produced. However I may act in this way, I am bound to get a motion which gives alternate currents. If I use a bar of iron surrounded by a coil of wire and magnetize it, with the north at one end and the south at the other end

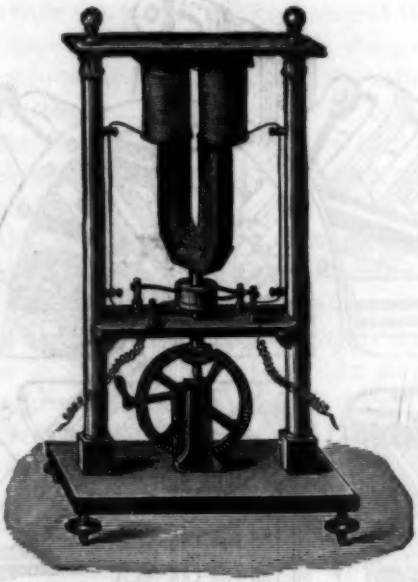

FIG. 6.—Pixii's machine.

I get a current, but it is impossible for me to keep that current going because I cannot get beyond a certain amount of magnetization. If I reverse the magnetization I produce a current in the opposite direction at the moment of reversal.

It would seem then that we have the power of producing currents alternating in direction. This was the only type of machine known for a considerable time; and all of you have seen those instruments in which a handle was turned rapidly while a person held the ends of the wire in his hand and received a succession of severe shocks; that was due to the production of alternate currents by an arrangement which alternately magnetized and demagnetized the iron core inside the coil.

I will now show you some illustrations on the screen which show

the construction of machines for producing alternate currents in this manner.

This in one of the alternate current machines, like that of Pixii or Saxton (Fig. 6). Here we have a horse-shoe magnet fixed about an axis to which a rapid rotation can be given. At the top are two coils which remain fixed, and inside these coils there are bars of iron. The consequence of this is that when the magnet is rapidly rotated the

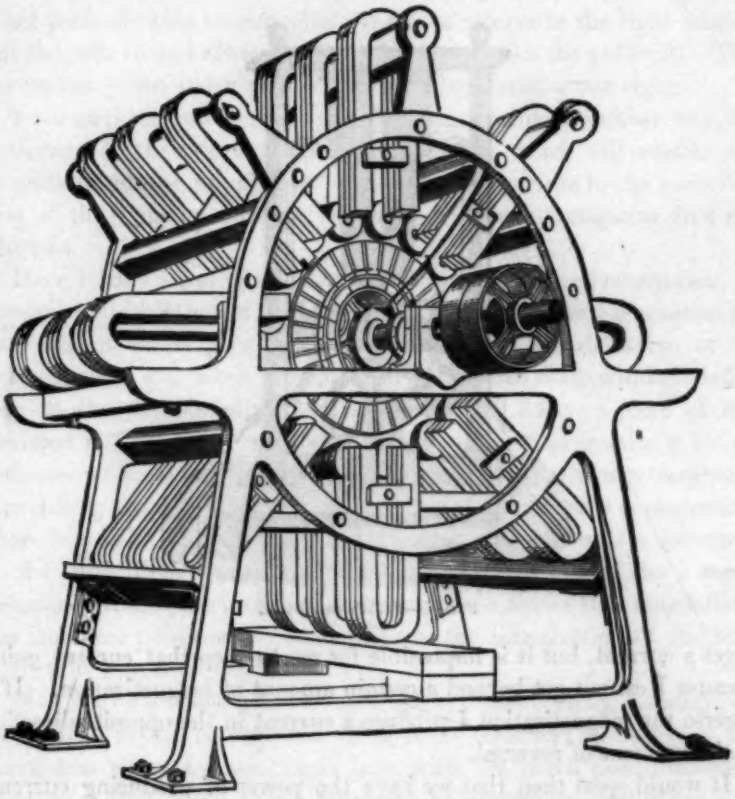

FIG. 7.—The Alliance machine for alternate currents.

north pole and the south pole will be successively presented to the coils, and the result is a continual reversal of the magnetism in those coils; and every time the magnetism is reversed a current is created in one direction or the other; and if the wires in these coils are held in the hand, a succession of violent shocks will be felt by the person hold-

ing them. One of the original machines of this type is shown in the historical collection in this exhibition.

I will put into the lantern another slide, showing a different form of machine. Here again is a horse shoe magnet. The magnet does not revolve, but the coils of wire revolve in front of the poles of the magnet. Here are the two coils at the bottom mounted upon a spindle which is horizontal. These two coils are rotated rapidly. Inside the coils are cores of iron. The cores of iron are magnetized in opposite directions as they pass from one pole of the fixed magnet to the other pole, and every time they do so, the current is changed in direction. Here also we are able to receive shocks from the coils by holding the ends of the wire in the hand. In this machine, as constructed, there was an arrangement for changing the direction of the current in the outer circuit at the same time that the magnetism was changed, but of that I will speak later.

In the next slide I shall show you the most practical of all the older machines (Fig. 7). This was the Alliance Machine used for lighthouses in Great Britain and France. It consists of a vast number of horse-shoe magnets. This machine has actually been employed in in our lighthouses in France and England. At the present moment you may see a machine made by De Meritens which is exhibited by James W. Queen & Co., at the far end of this Exhibition and which is constructed on the same principle.

A large number of rows of horse-shoe magnets are about this central axis, around which also there is a ring of coils of wire each with iron enclosed, and all these coils pass in succession the poles of the magnets and so alternate currents are created in the coils which produce a current of great intensity. These powerful currents are generated by means of a steam engine and so we were able to get the powerful spark of the arc lamp like what was seen by Sir Humphrey Davy, in 1811.

I may now pass on rapidly to the greatest improvement which was introduced, and that was the continuous current machine. It was found possible to take these currents from the machine which were alternately in opposite direction and reverse their direction through the circuit, that is to say through an arc lamp or through the hands of the person holding the wires, and thus a continuous current always in the same direction was made. A single reversal, however, did not produce a steady current and it was a long time afterwards before means were devised for creating a steady current which was of real use in produc-

ing these continuous currents which we now use in electric lighting, and in this country in telegraphy.

The greatest improvement was introduced by Mr. Gramme about the year 1870, and he did this by means of a machine, a diagram of which you can see on the board here. This is only a rough diagram showing the principle of the machine. (Fig. 8.)

Here is the north pole of the field-magnet, marked "*N*," and here is the south pole, marked "*S*." These are magnetized by coils going around the mass of iron. Here is a ring of iron with coils of wire wound around it. This is the armature. The iron of the ring becomes magnetized by the influence of these north and south poles of the field

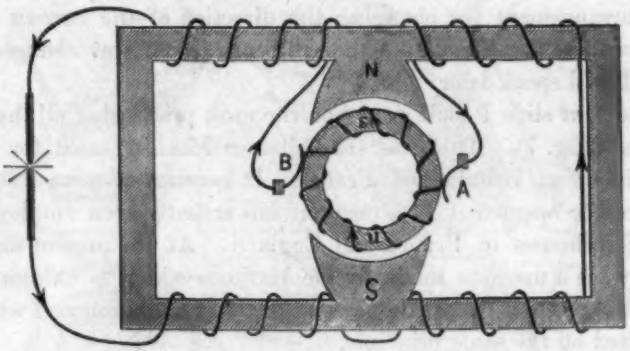

FIG. 8.—Diagram of Gramme machine (series wound), showing field-magnet and pole pieces, ring armature, commutator, and direction of currents. The armature rotates with the hands of a watch.

magnet and the poles in the ring retain the same position in space while the ring revolves. As soon as the ring rotates it follows that these wire coils are continually passing over the pole, or I might say this pole in the iron is continually passing through the coils. In other words, an electric current is being continually developed through successive coils as they pass through here.

If you look at the sketch you will see that there is a south pole in the ring at *s* opposite to the north pole in the field magnet, and a north pole in the ring at *n* opposite to the south pole of the field magnet. If you remember the rule I have given you about the direction of currents you will be able to trace their direction in the machine. Suppose the ring to be revolving in the direction of the hands of a watch, the north pole will be going in the opposite direc-

tion through the coils, and if the eye be placed so that the north pole is coming towards it the induced current circulates with the hands of a watch; with a south pole the reverse takes place. Follow this out and you will see that the current flows in the upper semicircle from *A* through *s* to *B*, and in the lower one from *A* through *n* to *B*. But the wire is continuous, and if metallic brushes take up the current at *A* and *B* you see that the current will go out of the armature coils at *B*, through the circuit, and in again at *A*.

Mr. Gramme constructed a commutator with a large number of bars to which the ends of these coils were connected, and he used metal brushes to rub on them, and thus there was a continual series of changes going on as each coil passed those brushes, and thus he was enabled to get a very continuous current of electricity through his machine.

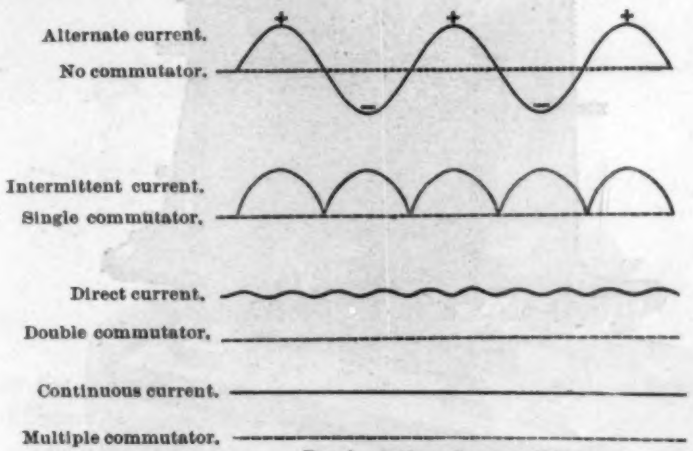

FIG. 9.—Action of commutators.

I have put up here a small diagram to illustrate the action of these commutators. (Fig. 9.) In the old alternate current machine there is a bobbin passing the poles of the magnet; the current increases to a maximum and falls to a minimum then increases to a maximum in the opposite direction when there is no commutator employed. When we put in a single commutator so as to reverse the current in each pole it rises to a maximum and falls to a minimum and we get this interrupted current, but always in the same direction. That was the first kind of continuous current made. Some machines were introduced to

give a double commutation that is twice commutated in the course of a revolution, and thus an irregular sort of current was produced; but when Gramme introduced his machine with a vast number of commutations in one revolution he had a vast number of currents and thus there is an almost continuous current produced by the Gramme machine.

In the Gramme machine which I showed you here, the current

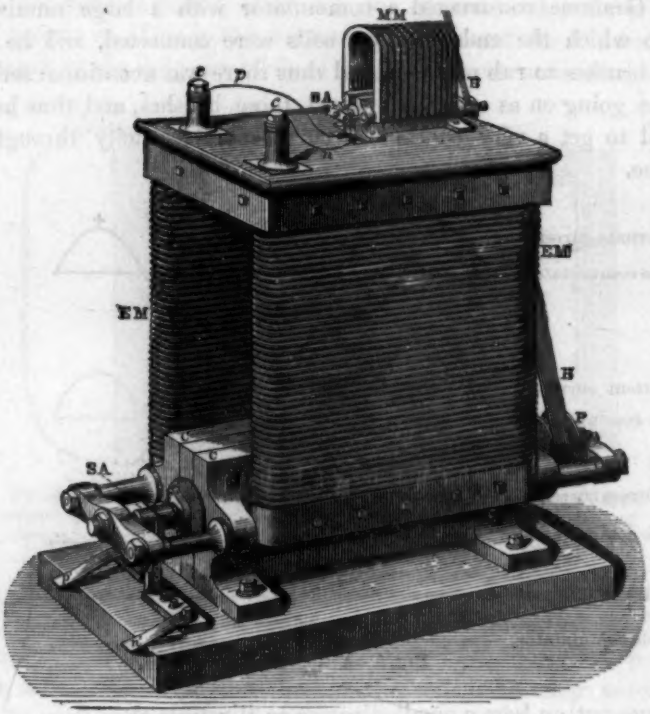

FIG. 10.—Wilde's magneto-electric machine.

itself is used to excite the magnetism in what are called the field magnets, and it passes through this field magnet before going to the lamp circuit. That is what is called winding the field magnets in series. Sometimes the current is taken direct from the revolving portion to the lamp circuit and a second current is taken to the field magnets forming two circuits and thus the field magnets are said to be magnetized in a shunt. The practice of using the current which is induced to

produce the magnetism of the field magnet was a completely new thing in 1866, and was invented simultaneously by several people, notably by Wheatstone and Siemens, who produced papers describing it on the same day in the Royal Society of London.

I will now show you on the screen a few more machines of the continuous current nature, including a Gramme machine, and some of the details of the Gramme machine, and I hope when you have seen these diagrams you will be able when going around this exhibition to study the nature of the different machines. It is in the arrangement of the field magnet and armatures in which the machines vary. The whole evening might be given to the variations of the different machines;

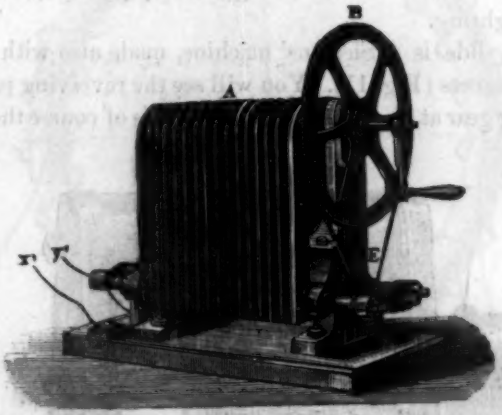

FIG. 11.—Siemens' machine.

in the meantime I can only show you a very few illustrations of the different types of machines.

The first machine which I have to show you here is the machine of Wilde (Fig. 10). Allow me to call your attention to the special parts. *S A* is the axis about which it revolves. In this revolving armature electricity is induced. This is the seat of the electro-motive force; this is the pump which pumps the water and gives it its pressure, and enables it to go through the circuit. *E M* are the magnets, which are composed of soft iron, magnetized by the coils of wire surrounding them. In Wilde's machine, he had a small machine, *M M*, with permanent steel magnets, fixed on top of the larger one. They are not so powerful magnets as these electro-magnets, and he used them to induce a small current of electricity instead of using the larger current to mag-

netize these electro-magnets. It created a feeble current, which circulated around these field magnets, and gave an intense magnetism to these pole pieces *C C*. These pole pieces being polarized, and the armature revolving, the coils of the armature developed an electric current of

FIG. 12.—Armature of Siemens' machine.

great intensity, far surpassing the current developed by the little machine. Thus he was enabled to get a very great current, sufficient for electric lighting.

This next slide is a Siemens' machine, made also with permanent horse shoe magnets (Fig. 11). You will see the revolving part attached to the driving gear at *E*. That revolving part is of course the armature;

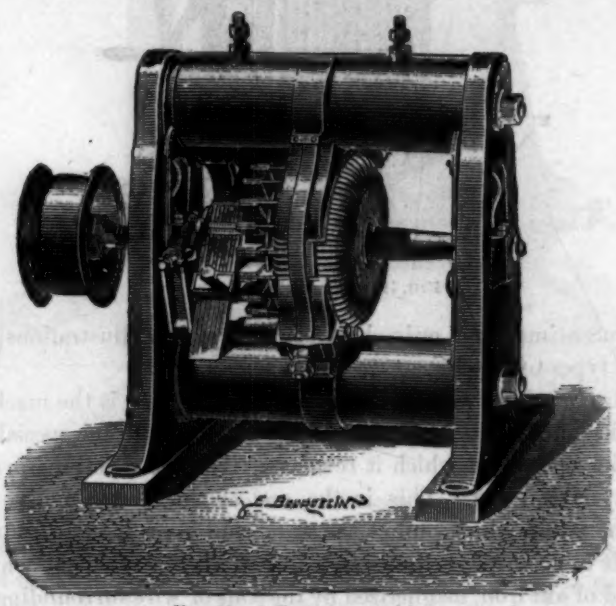

FIG. 13.—A Gramme machine.

the coils of the armature being between the pole pieces. This central part is a mass of iron, and the coils of wire run longitudinally around the core. (Fig. 12.) This machine, as originally constructed, had simply

a single commutator, which reversed the current once in each revolution, which sent a continuous but varying current through the circuit.

This slide (Fig. 13) is a Gramme machine, and was introduced to the public shortly after 1870, and this machine has been the basis of nearly all the dynamo machines seen in the world. These round parts at the bottom and top, surrounded by coils of wire, and the pole pieces seen at the top and bottom, are the magnets. There is the Gramme

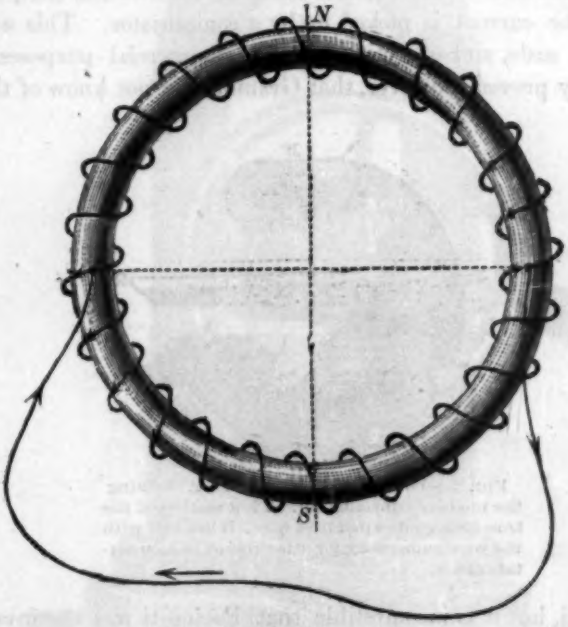

FIG. 14.—Ideal Gramme ring.

armature, which rotates about the horizontal axis, and here is the commutator.

This next picture is an ideal Gramme ring (Fig. 14). Here are are the successive coils. Here is the south and here is the north pole of the ring. You will notice that in each coil, as it passes the pole, an electric current is developed. The current will always be in the same direction, at any part of the ring, and very nearly continuous.

The next picture is a portion of a Gramme ring (Fig. 15). It shows the way it is made up; it consists of a central core of iron wire and coils of insulated wire successively laid upon it. It is cut, showing the ends of the wires projecting.

Here is a small Gramme machine, which can be worked by hand (Fig. 16). In construction it is exactly similar. Here are the poles; there is the revolving ring; the commutator is on the other side, and cannot be seen.

This picture is of a machine of very remarkable historical interest (Fig. 17). This was designed by Pacinotti, and described about the year 1864. It is exactly like a Gramme ring in many points. It revolves around a vertical axis instead of a horizontal axis, and as it revolves the current is picked up by a commutator. This was made on a small scale, and was not used for commercial purposes. It is conclusively proved, however, that Gramme did not know of the work

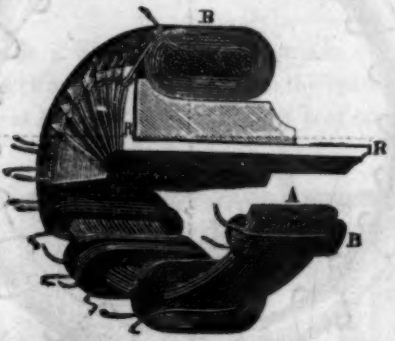

FIG. 15.—Portion of a Gramme ring, showing the mode of construction. A is a section of the iron ring made up of iron wire. B is a coil with the wire ends ready for attachment to commutator bars.

of Pacinotti, but it is incontestible that Pacinotti was the inventor of the type from which all the other machines have been constructed.

An attempt has been made to improve the constancy of the current, and prevent the difference in intensity which is observed when we are using a large or small number of lights. It is found with some kinds of machines that the intensity of the electro-motive force increases when we add lamps to the circuit, and in other kinds we find the opposite is the case. When the field-magnet of a machine is wound as a shunt, as we diminish the number of lamps, the lamps left burning increase in brightness. The machine which illuminates this hall is one with a shunt. It is the large Edison machine. This machine will not show the effect very much, because the armature of that machine is made of

very low resistance, and it is only lighting 300 lamps instead of 1,500; and the electro-motive force or pressure is steady, however we vary the number of lamps. Still it is a shunt-wound machine, and there is a slight difference between the intensity of the lights.

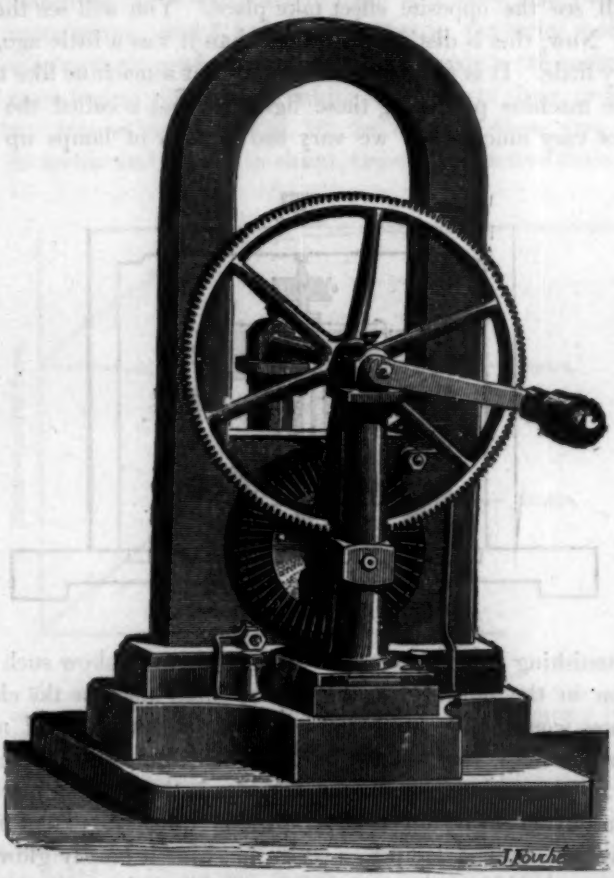

FIG. 16.—Hand Gramme machine.

I will now put out the lights in succession, and leave these two lamps to be last put out. You will notice that there is a slight increase in the brightness of the last two lights; it remains with you to notice that the change is very slight indeed. This illustrates how we can make a machine that will regulate itself; that is, however many lamps

we put upon the circuit the electrical pressure is the same and the intensity remains constant.

Now watch these two lights as the others are put out in succession. You see they are decidedly getting brighter. Put them in again and you will see the opposite effect take place. You will see them dimming. Now, this is distinctly dimmer than it was a little ago, though but very little. It is quite evident to you that a machine like the Edison (the machine producing these lights is what is called the Jumbo) does not vary much when we vary the number of lamps up to 300.

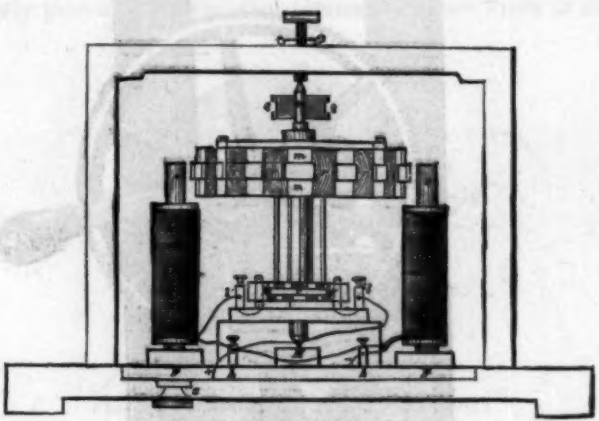

FIG. 17.—Pacinotti's machine.

It is astonishing when we descend to one lamp and show such a small variation in the light. In an ordinary small machine the change of brightness would have been decided. In the shunt wound machine, when we increase the number of lights we diminish the intensity of each. In the series machine the opposite is the fact. I might show you that experiment, but time is passing quickly. That is to say, when we put in one lamp in a series machine it hardly glows at all. The reason is that the current is very feeble with one lamp, because the resistance in the circuit is very great. When the current is feeble the magnetism of the field magnets is feeble, and that is the cause of the low electro-motive force. As I increase the number of lamps I am increasing the means of escape; that is, I am increasing the number of pipes of my hydraulic system, and letting more water flow, and the magnetization is more complete.

Of late years it has been earnestly attempted to produce perfect

equality even in the small machines, and without going to the vast dimensions of the large-size Edison machines, by winding the field magnet in a double way, partly as series machine and partly as shunt machine. I have already explained to you that when we have a shunt-wound machine the electro-motive force gradually diminishes as we put in more lamps; and I have shown that in the series machine the electro-motive force gradually increases as we reduce the resistance and put in more lamps. Therefore, taking the mean of these, or summing these two curves together (Fig. 18), by winding these two magnets partly in series and partly in shunt, the electro-motive force does not

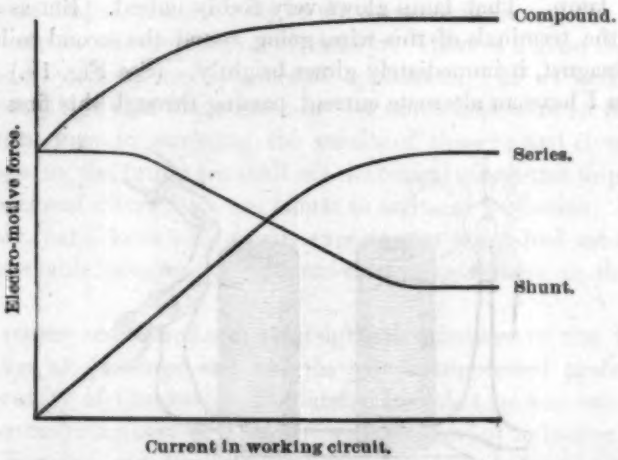

FIG. 18.—Showing relative advantage of compound winding in maintaining the electro-motive force constant when the current is changed.

vary in so great a degree. Thus we are able to get by a proper adjustment a perfect equality or difference of potential between the two parts of the line, and, whether we are dealing with the terminals, at the machine itself, or where the lamps are applied a mile away, by a proper compound winding, partly in series and partly in shunt, we are able to produce a compound machine which gives a constant electro-motive force however many lamps we are using, that is, however many pipes we may have drawing off water from our supply.

I had hoped to have spoken about the effects of alternate current machines, which would have been extremely interesting; but time is passing so rapidly that it is impossible to deal with this subject now.

I will only show you one remarkable experiment by means of the alternate current passed through a coil of wire on one arm of the electro magnet and through an incandescent lamp.

I will show these effects, because they are very remarkable. The effects of the alternate current machines are very difficult to understand at first sight. Perhaps, if I explain to you this one action I may have given some information to some of my audience here, and it may enable them to see some of the difficulties to be met with in alternate current machines, and enable them to avoid making mistakes in their applications in the future. I will pass an alternate current through one coil of the electro-magnet, and also through one incandescent lamp. That lamp glows very feebly indeed. But as soon as I join the terminals of this wire, going round the second coil of the electro-magnet, it immediately glows brightly. (See Fig. 19.)

When I have an alternate current passing through this first core, it

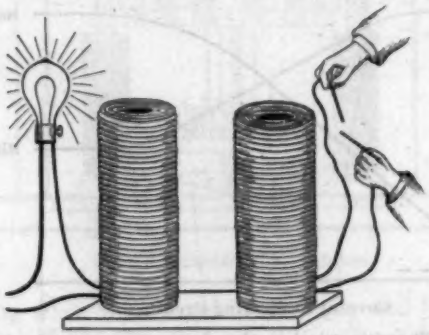

FIG. 19.—An alternate current passing through one arm of an electro-magnet and an incandescent lamp. When the ends of the other coil are separated the lamp is dull; when joined the lamp is bright.

is exercising a large power in magnetizing and demagnetizing that core. That core exercises its influence upon the other core to magnetize and demagnetize it. Thus the iron in these two arms of the magnet is being magnetized and demagnetized with great rapidity, and it is taking away from the current which is feeding this lamp. But so soon as I connect the wires of this other coil I am using up the power and magnetism in this core. I am making it do work in creating currents in this second coil; that is to say, this second coil acts as a drag on the magnetism of the core. So soon, then, as I connect the

ends of the wire of this second coil the magnetism cannot change there so suddenly, and the primary current is not able to do so much work in the magnet, and therefore it is more free to exert its own force, and therefore it enables the lamp to glow with greater brightness than it did before.

I must not trespass upon your time longer; I feel that I have already exhausted the limits which I had set myself, and which ought to be set to a lecture of this kind. On the subject of dynamo-electric machines several lectures might advantageously be given. We have, I think, advanced a great distance in the way of theoretical application of the laws of electricity to the dynamo-electric machines; we owe a great deal of this not only to the advance in theory, but also to the advance in the application of theory. There is a great deal still to be done by theory and by practical application. If we look to the past we shall find that there has been too much hesitation on the part of practical men in accepting the results of theory; and if we look with hope to the future we shall see theoretical views put to practice to guide us and direct us in our efforts to arrive at perfection. In fact I may say that I have seen private experiments which lead me to predict remarkable progress in dynamo-electric machinery in the near future.

On a recent occasion Lord Rayleigh, the president of the British Association, at Montreal, and also the very distinguished professor at the University of Cambridge, England, stated that he was astonished to find, considering how well known were the laws of induction in the time of Faraday, and how complete was our knowledge of electrical induction in those years long past, he was astonished to find at how slow a rate the practical applications of those principles long ago published by Faraday had been introduced into every-day work. Lord Rayleigh then stated his opinion that the cause of this slowness to apply the achievements of science was due to want of faith, and I agree with him that this is the true solution of the enigma. Faraday was a man whose mind was taken up with original investigation. Faraday had as complete a mathematical conception of the theory of electricity as any of us who have studied Clerk Maxwell's book could have; although he could not express one word of his ideas in terms of x, y and z. And in this way from the experiment of Oersted he was able to divine in his own mind the consequences of that experiment, and foresee the results of his own experiments in developing electro-magnetic induction; whereas you would have thought it was only by the

application of the higher mathematics that this could have been done. He also had this peculiarity, that he knew what his bent was, and in what manner he could be of the most benefit to mankind. He says himself, in one of his writings, as much as this. In speaking of the possible applications, and throwing out a hint as to the manner in which powerful dynamo-electric currents might be created, he makes use of the following language: "But in all my work it has been my endeavor not to seek out applications in practice so much as to arrive at new principles." I speak from memory, but I think these are nearly the words that appear in his "Researches." This was the key to his life. He knew that he had an inherent power to discover new principles, and that if he left the applications to others they would come in time.

In this past history of the applications of electricity we have thus to remember that thirty, forty and even fifty years ago we had the knowledge which was given us by Faraday, which would have enabled us to construct this dynamo-electric machine, and it was only through want of faith in those whose duty it is to deal with the applications of scientific facts that the slowness has been due. And in future let it be hoped that theory and application will work hand in hand, and that, while theorists see that the value of their investigations and the impetus which prompts them are due to their practical application, so others whose duty it is to apply science commercially may see that the rapidity of these applications depends upon the acceptance of the results of theory; and if this exhibition and this course of lectures lead those who apply science to study a little more fully the new ideas which theory is teaching us, and if they lead theorists to see a wider range for the applications of theory, then the managers of this Institute will have had the best reward possible for giving these lectures in knowing that they have been of some avail.

Mr. Joseph M. Wilson:—We are all so very much indebted to Prof. Forbes for his exceedingly interesting lecture, that I feel I am only expressing the sentiments of those present when I move that a vote of thanks be extended him, to be indicated by the audience rising.

The motion was seconded by Dr. William H. Wahl, and was unanimously adopted.

Note.—A number of the illustrations in Prof. Forbes' lecture are from "*Schellen* (*Keith*), *Magneto and Dynamo-Electric Machines*, for the use of which the Journal is indebted to the politeness of the publisher, D. Van Nostrand, New York.

STEAM BOILERS AS MAGAZINES OF EXPLOSIVE ENERGY.

By Professor Robert H. Thurston.

[A paper read before the American Society of Mechanical Engineers, October, 1884.]

Section I.—Computation of Stored Energy.

In the following paper it is proposed to present the results of a series of calculations relating to the magnitude of the store of energy contained in masses of steam and of water, when heated to temperatures customarily met with in the various applications of the expansive power of steam, in the arts, and especially in steam boilers. This energy may be measured by the amount of work which may be obtained by the gradual reduction of the temperature of the mass to that due atmospheric pressure by continuous expansion.

The subject is one which has often attracted the attention of both the man of science and the engineer. Its importance, both from the standpoint of pure science and from that of science applied in engineering and the minor arts, is such as would justify the expenditure of vastly more time and attention than has ever yet been given it. The first attempt to calculate the amount of energy latent in steam boilers, and capable of greater or less utilization in expansion by explosion, was made by Mr. George Biddle Airy,* the Astronomer Royal of Great Britain, in the year 1863, and by the late Professor Rankine† at about the same time. Mr. Airy and Professor Rankine published papers on this subject in the same number of the *Philosophical Magazine* (Nov., 1863), the one dated the 3d of September and the other the 5th October of that year. The former had already presented an abstract of his work at the meeting of the British Association of that year.

In the first of these papers, it is remarked that "very little of the destructive effect of an explosion is due to the steam which is confined in the steam-chamber at the moment of the explosion. The rupture of the boiler is due to the expansive power common at the moment to the steam and the water, both at a temperature higher than the boiling point; but as soon as the steam escapes, and thereby diminishes the

* "Numerical Expression of the Destructive Energy in the Explosions of Steam Boilers."

† "On the Expansive Energy of Heated Water."

compressive force upon the water, a new issue of steam takes place from the water, reducing its temperature; when this escapes, and further diminishes the compressive force, another issue of steam of lower elastic force from the water takes place, again reducing its temperature; and so on, till at length the temperature of the water is reduced to the atmospheric boiling point, and the pressure of the steam (or rather the excess of steam-pressure over atmospheric pressure) is reduced to 0."

Thus it is shown that it is the enormous quantity of steam so produced from the water, during this continuous but exceedingly rapid operation, that produces the destructive effect of steam-boiler explosions. The action of the steam which may happen to be present in the steam-space at the instant of rupture is considered unimportant.

Mr. Airy had, as early as 1849, endeavored to determine the magnitude of the effect thus capable of being produced, but had been unable to do so in consequence of deficiency of data. His determinations, as published finally, were made at his request by Professor W. H. Miller. The data used are the results of the experiments of Regnault and of Fairbairn and Tate, on the relations of pressure, volume and temperature of steam, and of an experiment by Mr. George Biddle, by which it was found that a locomotive boiler, at four atmospheres pressure, discharged one-eighth of its liquid contents by the process of continuous vaporization above outlined, when, the fire being removed, the pressure was reduced to that of the atmosphere. The process of calculation assumes the steam so formed to be applied to do work expanding down to the boiling point, in the operation. The work so done is compared with that of exploding gunpowder, and the conclusion finally reached is that "the destructive energy of one cubic foot of water, at a temperature which produces the pressure of 60 lbs. to the square inch, is equal to that of one pound of gunpowder."

The work of Rankine is more exact and more complete, as well as of greater practical utility. The method adopted is that to be described presently, and involves the application of the formulas for the transformation of heat into work which had been ten years earlier derived by Rankine and by Clausius, independently. This paper would seem to have been brought out by the suggestion made by Airy at the meeting of the British Association. Rankine shows that the energy developed during this, which is an adiabatic method of expansion, depends solely upon the specific heat and the temperatures at the beginning and the end of the expansion, and has no dependence, in any manner, upon

any other physical properties of the liquid. He then shows how the quantity of energy latent in heated water may be calculated, and gives, in illustration, the amount so determined for eight temperatures exceeding the boiling point. Approximate empirical expressions are given for the calculation of the energy and of the ultimate volumes assumed during expansion as follows, in British and in Metric measures:

$$U = \frac{772\,(T-212)^2}{T+1134{\cdot}4}; \qquad U_m = \frac{423{\cdot}55\,(T-100)^2}{T+648};$$

$$V = \frac{36{\cdot}76\,(T-212)}{T+1134{\cdot}4}; \qquad V_m = \frac{2{\cdot}29\,(T-100)}{T+648}.$$

These formulas give the energy in foot-pounds and kilogrammeters, and the volumes in cubic feet and cubic meters, T being taken on the common scale. They may be used for temperatures not found in the tables to be given, but, in view of the completeness of the latter, it will probably be seldom necessary for the engineer to resort to them.

This subject attracted the attention of the writer at a very early date. Familiarity, from early boyhood, with the destructive effects of steam boiler explosions, the singular mystery that has been supposed to surround their causes, the frequent calls made upon him, in the course of his professional practice and of his studies, to examine the subject and to give advice in matters relating to the use of steam, and many other hardly less controlling circumstances, invested this matter with an extraordinary interest. Probably no subject, within the whole range of the practice of the engineer has demanded or has received more attention than this; and probably no such subject is to-day less satisfactorily developed in theory and less thoroughly investigated experimentally than this. It is one which the writer has endeavored, at several different periods in the course of his work, to take up and reduce, if possible, to a consistent theoretical and practically applicable form. On each occasion, however, his labors were interrupted before they were fairly begun.

In the year 1872 the writer received from the Secretary of the Treasury of the United States a communication in which he was requested to prepare, for the use of the Treasury department, a report on the causes and the conditions leading to the explosions of steam boilers, and he began the preparation of such a report, in which he proposed to incorporate the facts to be here presented. In the year

1875, the writer, then a member of a commission formed by the government to investigate the subject, was asked by the Cabinet officer having direction of the matter to accept the chairmanship of the commission and to give his time to the subject under investigation. For sufficient reasons he was unwilling to undertake the work, and, an older and wiser head was appointed, at his request. A little later, ill health compelled him to resign from the commission; but his brief connection with the board led them to the further study of the subject of this paper; the investigation was, however, again interrupted, and has not since been taken up in the systematic manner then proposed.

In this paper, it is proposed to limit the subject to the investigation of the quantity of energy stored in some of the familiar and commonly used forms of steam boilers which are now everywhere seen endangering, to a greater or less extent, the lives and property of all who may be either permanently or temporarily within range of them.

A steam boiler is a vessel in which is confined a mass of water, and of steam, at a high temperature, and at a pressure greatly in excess of that of the surrounding atmosphere. The sudden expansion of this mass from its initial pressure down to that of the external air, occurring against the resistance of its "shell" or other masses of matter, may develop a very great amount of work by the transformation of its heat into mechanical energy, and may cause, as daily occurring accidents remind us, an enormous destruction of life and property. The enclosed fluid consists, in most cases, of a small weight of steam and a great weight of water. In a boiler of a once common and still not uncommon marine type, the writer found the weight of steam to be less than 250 pounds (114 kilogs.) while the weight of water was nearly 40,000 pounds (18,144 kilogs.). As will be seen later, under such conditions, the quantity of energy stored in the water is vastly in excess of that contained in the steam, notwithstanding the fact that the amount of energy per unit of weight of fluid is enormously the greater in the steam. A pound of steam, at a pressure of six atmospheres (88·2 pounds per square inch), above zero of pressure, and at its normal temperature, 177C. (319°F.), has stored in it about 125 British Thermal Units (32 Calories), or nearly 100,000 foot-pounds of mechanical energy (13,825 kilog. meters) per unit of weight, in excess of that which it contains after expansion to atmospheric pressure. A pound of water accompanying that steam, and at the same pressure, has stored within it but about one-sixteenth as much available energy. Never-

theless, the disproportion of weight of two fluids is so much greater as to make the quantity of energy stored in the steam contained in the boiler quite insignificant in comparison with that contained in the water. These facts will be fully illustrated by the figures to be hereafter presented.

The quantity of work and of energy which may be liberated by the explosion, or utilized by the expansion, of a mass of mingled steam and water has been shown by Rankine and by Clausius, who determined this quantity almost simultaneously, to be easily expressed in terms of the two temperatures between which the expansion takes place.

When a mass of steam, originally dry, but saturated, expands from an initial absolute temperature, T_1, to a final absolute temperature, T_2, if J is the mechanical equivalent of the unit of the heat and H is the measure, in the same units, of the latent heat per unit of weight of steam, the total quantity of energy exerted by unity of weight of the expanding mass is, as a maximum,

$$U = JT_2\left(\frac{T_1}{T_2} - 1 - \text{hyp. log. } \frac{T_1}{T_2}\right) + \frac{T_1 - T_2}{T_1} H. \qquad \text{(A)}.$$

This equation was published by Rankine a generation ago.*

When a mingled mass of steam and water similarly expands, if M represents the weight of the total mass and m is the weight of steam alone, the work done by expansion will be measured by the expression,

$$U = M J T_2\left(\frac{T_1}{T_2} - 1 - \text{hyp. log. } \frac{T_1}{T_2}\right) + m \frac{T_1 - T_2}{T_2} H \qquad \text{(B)}.$$

This equation was published by Clausius in substantially this form.†

It is evident that the latent heat of the quantity m, which is represented by mH, becomes zero when the mass consists solely of water, and that the first term of the second member of the equation measures the amount of energy of heated water which may be set free, or converted into mechanical energy by explosion. The available energy of heated water, when explosion occurs is thus easily measurable.

As has already been stated, this method was first applied by Rankine to the determination of the available energy of heated water for several selected temperatures and pressures. It has long been the intention of the writer to ascertain the magnitude of the quantities of energy

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* Steam Engine and Prime Movers, p. 387.

† Mechanical Theory of Heat, Browne's Translation, p. 283.

residing, in available form, in both steam and water, for the whole usual range of temperatures and pressures familiar to the engineer, and also to carry out the calculations for temperatures and pressures not yet attained, except experimentally, but which are likely to be reached in the course of time, as the constantly progressing increase now observable goes on. The maximum attainable, in the effort to increase the efficiency of the steam engine and in the application of steam to new purposes, cannot be to-day predicted, or even, so far as the writer can see, imagined. High pressures like those adopted by Perkins and by Alban may yet be found useful. It was therefore proposed to carry out the tables to be constructed far beyond the limit of present necessities.

It was further proposed to ascertain the weights of steam and of water contained in each of the more common forms of steam boilers, and to determine the total and relative amounts of energy confined in each under the usual conditions of working in every-day practice, and thus to ascertain their relative destructive power in case of explosion. This part of the work is reserved for description in a succeeding section of this paper. The present section is devoted to the first part of the subject.

At the commencement of this work, the writer employed the late Mr. W. G. Cartwright, M. E., as computer, and, with his aid, prepared tables extending from 50 pounds per square inch to 100, at intervals of ten pounds, up to 250 with intervals of 25 pounds, then 300, and up to 1,000 pounds per square inch by 100 pounds, and with larger intervals up to 10,000 and 20,000 pounds. The available energy of the heated water was computed, the energy obtainable from the so-called "latent heat," and their sum, *i.e.*, the available energy of steam per unit of weight. In the course of this work, each figure was calculated independently by two computers, and thus checked. As a further check, the figures so obtained were plotted, and the curve representing the law of their variation was drawn. This was a smooth curve of moderate curvature and an incorrect determination was plainly revealed, and easily detected, by falling outside the curve. Three curves were thus constructed which will be given later: (1) the Curve of Available Energy of Heated Water; (2) the Curve of Available Energy of Latent Heat; (3) the Curve of Available Energy of Steam. The second of these curves presents an interesting peculiarity which will be pointed out when studying the forms of the several curves and the tables of results.

The work was interrupted by more pressing duties, and was finally resumed in the spring of 1884 and completed in the form now presented. The computers of the more complete tables here given were Messrs. Ernest H. Foster, M. E., and Kenneth Torrance, M. E., who, pursuing the same method as was originally adopted for the earlier computations, have revised the whole work, recalculating every figure, extending the tables by interpolation, and carrying them up to a still higher pressure than was originally proposed. The tables here presented range from 20 pounds per square inch, (1·4 kgs. per sq. cm.) up to 100,000 pounds per square inch (7,030.83 kgs. per sq. cm.) the maximum probably falling far beyond the range of possible application, its temperature exceeding that at which the metals retain their tenacity, and, in some cases, exceeding their melting points. These high figures are not to be taken as exact. The relation of temperature to pressure is obtained by the use of Rankine's equation, of which it can only be said that it is wonderfully exact throughout the range of pressures within which experiment has extended, and within which it can be verified. The values estimated and tabulated are probably quite exact enough for the present purposes of even the military engineer and ordnance officer. The form of the equation, and of the curve representing the law of variation of pressure with temperature, indicates that, if exact at the familiar pressures and temperatures, it is not likely to be inexact at higher pressures. The curve, at its upper extremity, becomes nearly rectilinear.

The table which follows presents the values of the pressures in pounds per square inch above a vacuum, the corresponding reading of the steam gauge (allowing a barometric pressure of 14·7 pounds per square inch), the same pressures reckoned in atmospheres, the corresponding temperatures as given by the Centigrade and the Fahrenheit thermometers, and as reckoned both from the usual and the absolute zeros. The amount of the explosive energy of a unit weight of water, of the latent heat in a unit weight of steam, and the total available heat energy of the steam, are given for each of the stated temperatures and pressures throughout the whole range in British measures, atmospheric pressures being assumed to limit expansion. The values of the latent heats are taken from Regnault, for moderate pressures, and are calculated for the higher pressures, beyond the range of experiment, by the use of Rankine's modification of Regnault's formula.

TABLE I.—AVAILABLE STORED ENERGY IN WATER AND STEAM.

Pressure above a Vacuum in pounds per square inch.	Same pressure as indicated by steam gauge, allowing 14·7 lbs. for atmospheric pressure.	Absolute pressure in atmospheres.	Number of British Thermal units to be given for the evaporation of one pound of water, known as latent heat of evaporation, H.	Temperature in degrees Fahrenheit of the steam and of the water from which it is evaporated.	Temperature in degrees Centigrade of the steam and of the water from which it is evaporated.	Corresponding absolute temperature in degrees Fahrenheit.	Corresponding absolute temperature in degrees Centigrade.	Amount of energy contained in one pound of water which may be liberated by expansion or explosion to 212° Fahr.	Corresponding am't of energy contained in the latent heat of evaporation.	Total amount of energy contained in one pound of steam at corresponding temperatures and pressures.
20	5·3	1·36	954·415	227·9	108·8	680·0	382·8	145·9	16872·9	17018·8
25	10·3	1·70	945·825	240·0	115·5	701·2	389·5	439·7	29156·8	29596·5
30	15·3	2·04	938·925	250·2	121·2	711·4	395·2	813·5	38921·9	39735·4
35	20·3	2·38	932·1523	259·1	126·1	720·3	400·1	1225·4	47064·9	48278·3
40	25·3	2·72	926·1728	267·1	130·1	728·3	404·6	1645·7	54111·7	55757·4
45	30·3	3·06	921·8343	274·2	134·5	735·4	408·5	2113·9	60158·1	62271·0
50	35·3	3·40	916·6316	280·8	138·2	742·0	412·2	2550·4	66013·8	68564·2
55	40·3	3·74	912·2906	286·8	141·6	748·0	415·6	2986·9	70428·6	73428·6
60	45·3	4·08	908·2472	292·5	144·7	753·7	418·7	3449·2	74884·6	78333·8
65	50·3	4·42	904·4621	297·7	147·6	758·9	421·6	3899·8	78950·5	82750·3
70	55·3	4·76	900·8991	302·7	150·4	763·9	424·4	4361·1	83577·7	88938·8
75	60·3	5·10	897·5269	307·3	152·9	768·5	426·9	4815·8	85923·6	90739·4
80	65·3	5·44	894·3304	311·8	155·4	773·0	429·4	5306·5	89138·7	94445·2
85	70·3	5·78	891·2962	316·0	157·7	777·2	431·7	5628·9	92078·3	97712·2
90	75·3	6·12	888·3756	320·0	160·0	781·2	434·0	6058·1	94814·7	100872·8
95	80·3	6·46	885·5867	323·8	162·1	785·0	436·1	6474·2	97447·2	103921·4
100	85·3	6·80	882·9144	327·5	164·1	788·7	438·1	6885·2	99757·6	106642·8
105	90·3	7·14	880·3429	331·1	166·1	792·3	440·1	7290·3	102163·3	109453·6
110	95·3	7·48	877·8653	334·5	168·0	795·7	442·0	7689·0	104384·9	112073·9
115	100·3	7·82	875·4721	337·8	169·8	799·0	443·8	8087·3	106421·7	114509·0
120	105·3	8·16	873·1595	340·9	171·6	802·1	445·6	8483·1	108385·4	116868·5
125	110·3	8·50	870·9115	344·0	173·3	805·2	447·3	8864·9	110219·9	119084·8
130	115·3	8·84	868·7251	347·0	175·0	808·2	449·0	9252·6	112025·6	121278·2
135	120·3	9·18	866·6223	349·9	176·6	811·1	450·6	9627·0	113745·7	123372·7
140	125·3	9·52	864·5661	352·7	178·1	813·9	452·1	9992·6	115382·1	125374·7
145	130·3	9·86	862·5679	355·5	179·7	816·7	453·7	10361·0	117003·5	127364·5
150	135·3	10·20	860·6213	358·1	181·1	819·3	455·1	10736·5	118477·2	129063·7
155	140·3	10·54	858·7276	360·7	182·6	821·9	456·6	11085·9	119939·4	131025·3
160	145·3	10·88	856·8740	363·2	184·0	824·4	458·0	11444·2	121338·6	132787·8

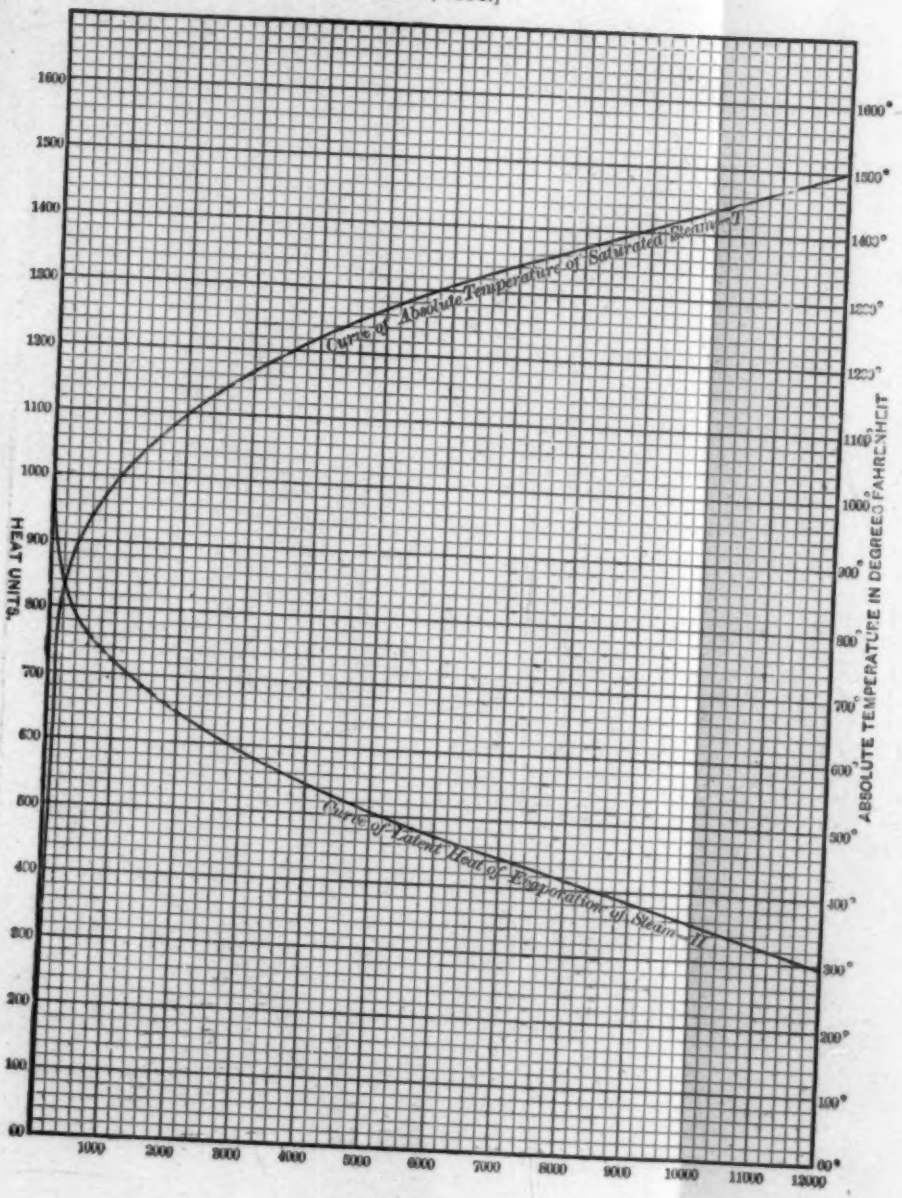
TABLE I.—AVAILABLE STORED ENERGY IN WATER AND STEAM.—*Continued.*

Pressure above a vacuum in pounds per square inch.	Same pressure as indicated by steam gauge, allowing 14·7 lbs. for atmospheric pressure.	Absolute pressure in atmosphere.	Number of British Thermal units required for the evaporation of one pound of water, known as latent heat of evaporation, H.	Temperature in degrees Fahrenheit of the steam and of the water from which it is evaporated.	Temperature in degrees Centigrade of the steam and of the water from which it is evaporated.	Corresponding absolute temperature in degrees Fahrenheit.	Corresponding absolute temperature in degrees Centigrade.	Amount of energy contained in one pound of water which may be liberated by explosion or expansion to 212° Fahr.	Corresponding amt. of energy contained in the latent heat of evaporation.	Total amount of energy contained in one pound of steam at corresponding temperatures and pressures.
165	150·3	11·22	855·0654	365·7	185·4	826·9	459·4	11823·4	123997·8	134521·2
170	155·3	11·56	853·2942	368·1	186·7	829·3	460·7	12141·3	129866·5	136136·8
175	160·3	11·90	851·5670	370·5	188·0	831·7	462·0	12508·7	125284·7	137793·4
180	165·3	12·24	849·8808	372·8	189·3	834·0	463·3	12821·4	130849·1	138330·5
185	170·3	12·58	848·2306	375·0	190·5	836·2	464·5	13182·0	127642·4	140824·4
190	175·3	12·92	846·6244	377·2	191·7	838·4	465·7	13367·1	128778·8	142145·9
195	180·3	13·26	844·9988	379·4	193·0	840·6	467·0	13844·1	129668·3	143552·4
200	185·3	13·60	843·4526	381·5	194·1	842·7	468·1	14153·3	129071·4	145120·7
210	195·3	14·28	840·3807	385·6	196·4	846·8	470·4	14830·8	130008·2	147894·0
220	205·3	14·60	838·5664	389·8	198·7	851·0	472·7	15465·1	130003·3	151466·4
230	215·3	15·64	833·9091	391·2	201·2	855·4	475·2	16180·3	131134·2	153314·7
240	225·3	16·32	832·6410	397·0	203·3	859·1	477·3	16790·2	130004·3	156884·5
250	235·3	17·00	830·3630	401·0	205·0	862·2	479·0	17314·4	140516·0	157830·4
500	485·3	31·01	780·8502	467·6	242·0	926·8	516·0	30055·5	165892·7	195948·2
1000	985·3	66·02	720·4950	546·8	286·0	1006·0	560·0	49071·5	179212·0	227883·5
2000	1985·3	130·05	643·9949	639·8	337·6	1104·9	613·8	75777·2	194221·3	269998·5
3000	2985·3	194·08	590·8688	706·3	375·7	1169·5	649·7	96116·3	198555·0	294671·3
4000	3985·3	258·10	544·6774	763·7	405·9	1223·9	679·9	114498·6	189201·7	303700·3
5000	4985·3	322·13	505·7339	807·8	431·1	1269·0	705·1	130494·2	183905·9	313900·1
6000	5985·3	386·16	471·8473	845·9	452·1	1307·1	726·1	144413·4	176656·9	321070·3
7000	6985·3	450·19	439·9985	881·2	471·7	1342·4	745·7	157944·2	169833·3	327777·5
8000	7985·3	514·21	409·4833	914·3	490·1	1375·5	764·1	170632·0	161892·6	332524·6
9000	8985·3	612·24	382·6347	945·2	507·3	1406·4	781·5	182666·6	153742·6	336409·2
10000	9985·3	680·27	355·2491	971·4	521·8	1432·6	795·8	193787·0	145570·8	339164·2
100000	99985·3	6802·72	305·3040	2165·4	1184·1	2924·6	1468·1			

Studying the table, the most remarkable fact noted at the lower pressures is the enormous difference in the amounts of energy, in available form, contained in the water and in the steam, and between the energy of sensible heat and that of latent heat, the sum of which constitutes the total energy of the steam. At 20 pounds per square inch above zero (1·36 atmos.), the water contains but 145·9 foot-pounds per pound; while the latent heat is equivalent to 16,872.9 foot-pounds, or more than 115 times as much; *i. e.*, the steam contains 116 times as much energy in the form of heat per pound, as does the water, from which it is formed, at the same temperature. The temperature is low; but the amount of energy expended in the production of the molecular change resulting in the conversion of the water into steam is very great, in consequence of the enormous expansion then taking place. At 50 pounds, the ratio is 20 to 1; at 100 pounds per square inch, it is 14 to 1, at 500 it is 5 to 1; while at 5,000 pounds the energy of latent heat is but 1·4 that of the sensible heat. The two quantities become equal at about 7,500 pounds. At the highest temperature and pressure tabled, the same law would make the latent heat negative; it is of course uncertain what is the fact at that point.

At 50 pounds per square inch, the energy of heated water is 2550·4 foot-pounds, while that of the steam is 68,184, or enough to raise its own weight to a height in each case of a half mile or of 12 miles. At 75 pounds the figures are 4,816 and 90,739, or equivalent to the work demanded to raise the unit weight to a height of four-fifths, and of about 17 miles, respectively. At 100 pounds the heights are over one mile for the water, and above 20 miles for the steam.

Plotting the tabulated figures and determining the form of the curve representing the law of variation of each set, we obtain the peculiar set of diagrams exhibited in the accompanying engraving. In figure 1 are seen the curves of absolute temperature and of latent heat as varying with variation of pressure. They are smooth and beautifully formed lines, having no relation to any of the familiar curves of the text-books on co-ordinate geometry. In figure 2 are given the curves of available energy of the water, of latent heat, and of steam. The first and third have evident kinship with the two curves given in the preceding illustration; but the curve of energy of latent heat is of an entirely different kind, and is not only peculiar in its variation in radius of curvature, but also in the fact of presenting a maximum ordinate at an early point in its course. This maximum is


Curve of Absolute Temperature of Saturated Steam = T
Curve of Latent Heat of Evaporation of Steam = H
HEAT UNITS.
ABSOLUTE TEMPERATURE IN DEGREES FAHRENHEIT
FOOT POUNDS.
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
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100
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2000
3000
4000
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9000
10000
11000
12000

FIG. 1.

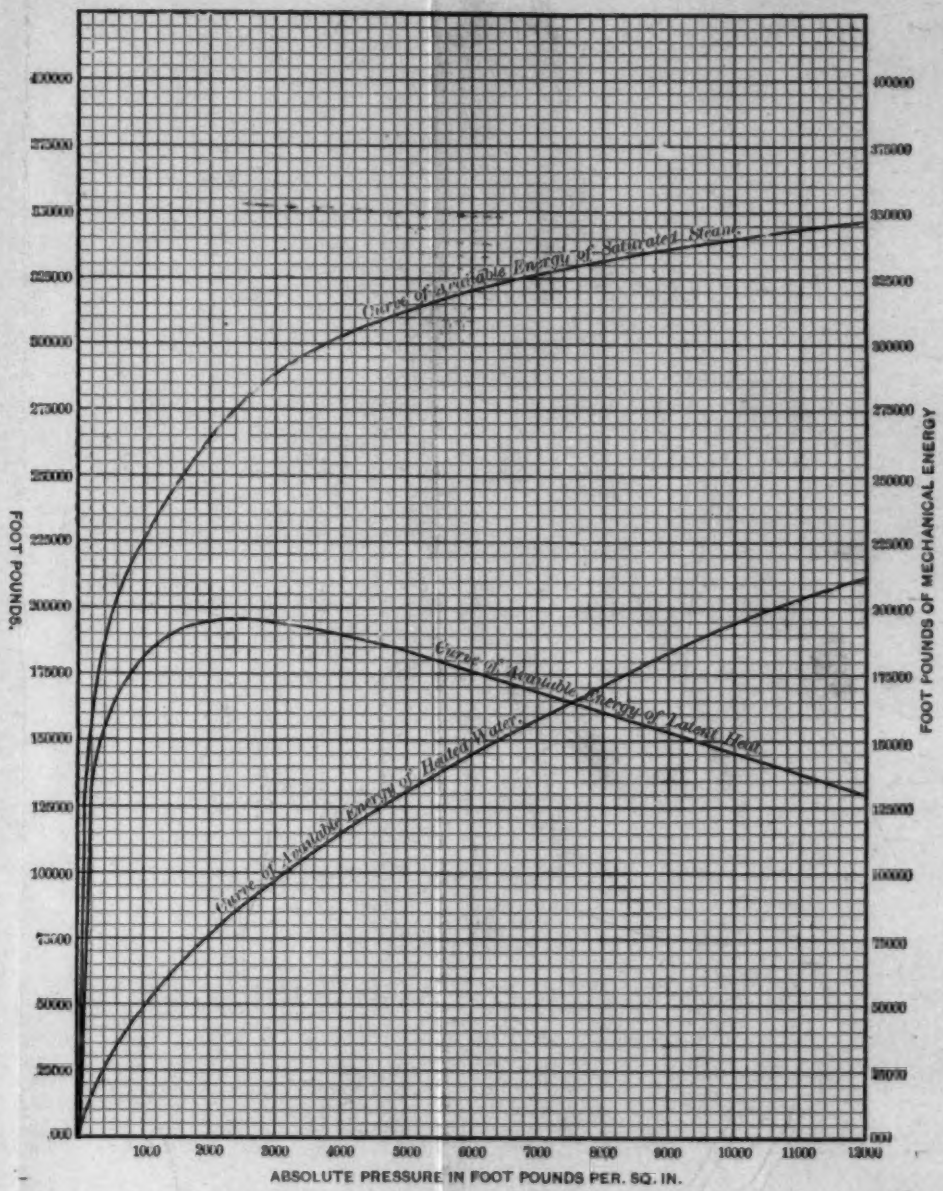
Curve of Available Energy of Saturated Steam.
Curve of Available Energy of Latent Heat.
Curve of Available Energy of Heated Water.
FOOT POUNDS.
FOOT POUNDS OF MECHANICAL ENERGY
400000
375000
350000
325000
300000
275000
250000
225000
200000
175000
150000
125000
100000
75000
50000
25000
000
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
ABSOLUTE PRESSURE IN FOOT POUNDS PER. SQ. IN.

FIG. 2.

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energy o
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pressure
as one p
sufficient
the water
At a low
energy in
pressure,
At 100
powder, a

found at a pressure of about one ton per square inch, a pressure easily attainable by the engineer.

Examining the equations of those curves it is seen that they have no relation to the conic sections, and that the curve, the peculiarities of which are here noted, is symmetrical about one of its abscissas, and that it must have, if the expression holds for such pressures, another point of contrary flexure at some enormously high pressure and temperature. The formula is not, however, a "rational" one, and it is by no means certain that the curve is of the character indicated; although it is exceedingly probable that it may be. The presence of this characteristic point, should experiment finally confirm the deduction here made, will be likely to prove interesting, and it may be important; its discovery may possibly prove to be useful. (See Fig. 2.)

The curve of energy of steam is simply the curve obtained by the superposition of one of the two preceding curves upon the other. It rises rapidily at first, with increase of temperature, then gradually rises more slowly, turning gracefully to the right, and finally becoming nearly rectilinear. The curve of available energy of heated water, exhibits similar characteristics; but its curvature is more gradual and more uniform.

Comparing the energy of water and of steam in the steam boiler, with that of gunpowder, as used in ordnance, it will be found that, at high pressures, the former become possible rivals of the latter. The energy of gunpowder is somewhat variable with composition and perfection of manufacture, and is very variable in actual use, in consequence of the losses in ordnance due to leakage, failure of combustion, or retarded combustion in the gun. Taking its value at what the writer would consider a fair figure, 250,000 foot-pounds per pound, it is seen that, as found by Airy, a cubic foot of heated water, under a pressure of 60 or 70 pounds per square inch, has about the same energy as one pound of gunpowder. The gunpowder exploded has energy sufficient to raise its own weight to a height of nearly 50 miles; while the water has enough to raise its weight about one-sixtieth that height. At a low red heat, water has about 40 times this latter amount of energy in a form to be so expended. One pound of steam, at 60 pounds pressure, has about one-third the energy of a pound of gunpowder. At 100 pounds it has as much energy as two-fifths of a pound of powder, and at higher pressures, its energy increases very slowly.

Section II.—Explosive Energy of Boilers.

In illustration of the results of application of the computations which have been given in the preceding section of this paper, and for the purpose of obtaining some idea of the amount of destructive energy stored in steam-boilers of familiar forms, such as the engineer is constantly called upon to deal with, and such as the public are continually endangered by, Table II, has been calculated. This table is made up, with the assistance of Professor C. A. Carr, from notes of dimensions of boilers designed, or managed, at various times, by the writer, or in other ways having special interest to him. They include nearly all of the forms in common use, and are representative of familiar and ordinary practice.

No. 1 is the common, simple, plain cylindrical boiler. It is often adopted when the cheapness of fuel or the impurity of the water-supply renders it unadvisable to use the more complex, though more efficient, kinds. It is the cheapest and simplest in form of all the boilers. The boiler here taken was designed by the writer many years ago for a mill so situated as to make this the best form for adoption, and for the reasons above given. It is thirty inches in diameter, thirty feet long, and is rated at ten HP., although such a boiler is often forced up to double that capacity. The boiler weighs a little over a ton, and contains more than twice its weight of water. The water, at a temperature corresponding to that of steam at 100 pounds pressure per square inch, contains over 46,600,000 foot-pounds of available explosive energy, while the steam, which has but one-fifth of one per cent. of the weight of the water, stores about 1,300,000 foot-pounds, giving a total of 48,000,000 foot-pounds, nearly, or sufficient to raise one pound nearly 10,000 miles. This is sufficient to throw the boiler 19,000 feet high, or nearly four miles, and with an initial velocity of projection of 1,111 feet per second.

Comparing this with the succeeding cases, it is seen that this is the most destructive form of boiler on the whole list. Its simplicity and its strength of form make it an exceedingly safe boiler, so long as it is kept in good order and properly managed; but, if through phenomenal ignorance or recklessness on the part of proprietor or attendant, the boiler is exploded, the consequences are usually exceptionally disastrous.

The explosion of a boiler of this form and of the proportions here

TABLE II.—*Stored Energy of Steam Boilers.*

Type.	Area of		Pressure lbs. per sq. in.	Rated power H. P.	Weight of			Stored energy in (available).			Energy per lb. of		Max h't of proj'tn		Initial velocity.	
	G.S.	H. S.			Boiler.	Water.	Steam.	Water.	Steam.	Total.	Boiler	Tot w't	Boiler	T'tl	Boiler	Total
	Sq. feet.				Lbs.			Foot lbs.			Foot lbs		Feet.		Ft. per sec.	
1. Plain Cylinder	15	120	100	10	2500	5764	11·325	46,605,200	1,297,380	47,902,580	19161	5879	19161	5879	1111	615
2. Cornish Cylinder	36	730	30	60	16950	27471	31·45	57,570,750	1,958,420	59,509,170	3511	1336	3511	1336	476	293
3. Two Flue Cylinder	20	400	150	35	6775	6840	37·04	80,572,050	4,544,730	85,116,780	12563	6235	12563	6253	900	634
4. Plain Tubular	30	851·97	75	60	9500	8255	20·84	50,008,790	2,102,190	52,110,980	5485	2932	5485	2932	595	435
5. Locomotive	22	1070	125	525	19400	5260	21·67	52,561,075	2,716,875	55,277,950	2849	2239	2849	2239	427	380
6. "	30	1350	125	650	25000	6920	31·19	69,148,790	3,910,450	73,059,240	2922	2287	2922	2287	434	384
7. "	20	1200	125	600	20565	6450	25·65	64,452,270	3,225,870	67,678,140	3291	2503	3291	2503	460	401
8. "	15	875	125	425	14020	6330	19·02	64,253,160	2,384,630	66,637,790	4753	3259	4753	3259	549	458
9. Scotch Marine	32	768	75	300	27045	11765	29·8	71,272,370	3,006,060	74,278,430	2747	1913	2747	1913	421	350
10. "	50·5	1119·5	75	350	37072	17730	47·2	107,408,340	4,761,210	112,169,550	2994	2012	2994	2012	439	360
11. Flue and Return Tubular	72·5	2324	30	200	56000	42845	69·81	90,531,490	4,347,140	94,878,610	1694	959	1694	959	330	248
12. " " " "	72	1755	30	180	56000	48570	73·07	102,628,410	4,550,140	107,178,550	1914	1024	1914	1024	351	257
13. Water Tube	70	2806	100	250	34450	21825	35·31	172,455,270	4,043,310	176,498,580	5123	3165	5123	3165	575	451
14. "	100	3000	100	250	45000	28115	58·5	227,366,000	6,719,980	234,085,980	5202	3177	5202	3177	579	452
15. "	100	3000	100	250	54000	13410	23·64	108,346,670	2,606,990	110,935,660	2054	1645	2054	1645	364	326

given, in the year 1843, in the establishment of Messrs. R. L. Thurston & Co., at Providence, R. I., through mismanagement, is well remembered by the writer. The boiler-house was entirely destroyed, the main building seriously damaged, and a large expense was incurred in the purchase of new tools to replace those destroyed. No lives were lost, as the explosion fortunately occurred after the workmen had left the building. A similar explosion of a boiler of this size occurred some years later, within sight of the writer, which drove one end of the exploding boiler through a 16-inch wall, and several hundred feet through the air, cutting off an elm tree high above the ground, where it measured 9 inches in diameter, partly destroying a house in its further flight, and fell in the street beyond, where it was found *red hot* immediately after striking the earth. Long after the writer reached the spot, although a heavy rain was falling, it was too hot to be touched and was finally, nearly two hours later, cooled off by a stream of water from a hose, in order that it might be moved and inspected. It had been overheated, in consequence of low water, and cold feed had then been turned into it. The boiler was in very good order, but four years old, and was considered safe for 110 pounds. The engineer was seriously injured, and a pedestrian passing at the instant of the explosion was buried in the ruins of the falling walls and killed. The energy of this explosion was very much less than that stored in the boiler when in regular work.

No. 2 was a "Cornish" boiler designed by the writer, about 1860, and set to be fired under the shell. It was 6 feet by 36, and contained a 36-inch flue. The shell and flue were both of iron $\frac{3}{8}$-inch in thickness. The boiler was tested up to 60 pounds, at which pressure the flue showed some indications of alteration of form. It was strengthened by stay-rings, and the boiler was worked at 30 pounds. The boiler contained about 12 tons of water, weighed itself $7\frac{1}{2}$ tons, and the volume of steam in its steam space weighed but $31\frac{1}{2}$ pounds. The stored available energies were about 57,600,000 foot-pounds, and about 2,000,000 of foot-pounds, in the water and steam, respectively, a total of nearly 60,000,000. This was sufficient to throw the boiler to the height of 3,500 feet, or over three-fifths of a mile.

Comparing this with the preceding, it is seen that the introduction of the single flue, of half the diameter of the boiler, and the reduced pressure, have reduced the relative destructive power to but little more than one-sixth that of the preceding form.

No. 3 is a "two-flue" or Lancashire boiler, similar in form and in proportions to many in use on the steamboats plying on our Western rivers, and which have acquired a very unenviable reputation by their occasional display of energy when carelessly handled. That here taken in illustration was designed by the writer, 42 inches in diameter, with two 14-inch flues of $\frac{3}{8}$ iron, and is here taken as working at a pressure, as permitted by law, of 150 pounds per square inch. It is rated at 35 horse-power, but such a boiler is often driven far above this figure. The boiler contains about its own weight, 3 tons, of water, and but 37 pounds of steam. The stored available energy is 85,000,000 foot-pounds, of which the steam contains but a little above five per cent. Its explosion would uncage sufficient energy to throw the boiler nearly $2\frac{1}{2}$ miles high, with an initial velocity of 900 feet per second. Both this boiler and the plain cylinder are thus seen to have a projectile effect only to be compared to that of ordnance.

A boiler of this class, which the writer was called upon to inspect after explosion, had formed one of a "battery" of ten or twelve, and was set next the outside boiler of the lot. Its explosion threw the latter entirely out of the boiler-house into an adjoining yard, displaced the boiler on the opposite side, and demolished the boiler-house completely. The exploding boiler was torn into many pieces. The shell was torn into a helical ribbon, which was unwound from end to end. The furnace end of the boiler flew across the space in front of its house, tore down the side of a "kier-house," and demolished the kiers, nearly killing the kier-house attendant, who was standing between two kiers. The opposite end of the boiler was thrown through the air, describing a trajectory having an altitude of fifty feet, and a range of several hundred, doing much damage to property *en route*, finally landing in a neighboring field. The furnace front was found by the writer on the top of a hill, a quarter of a mile, nearly, from the boiler-house. The fireman, who was on the top of the boiler at the instant of the explosion, endeavoring to open a steam connection to relieve the boiler, then containing an excess of steam and a deficiency of water, was thrown over the roof of the mill, and his body was picked up in the field on the other side, and carried away in a packing-box measuring about two feet on each side. Cause: low water and consequent overheating, and the introduction of feed before hauling fires and cooling down. The energy expended was much less than that calculated as above.

No. 4 is the common plain tubular boiler, substantially as designed

by the writer at about the same time with those already described, and of the same in dimensions as that adopted as a standard by the Hartford Steam Boiler Insurance Co.* It is a favorite form of boiler, and deservedly so, in the opinion of the writer, with all makers and users of shell boilers. That here taken is 60 inches in diameter, containing 66 3-inch tubes, and is 15 feet long. The general testimony of the best designers of this type, so far as the writer has been able to obtain definite opinions, as well as the observation and the experience of the writer himself, indicate that these proportions are usually thoroughly satisfactory. A length of tube of from 50 to 60 diameters, and liberal spacing, seem to be especially advantageous. The specimen here chosen has 850 feet of heating and 30 feet of grate surface, is rated at 60 horse-power, but is oftener driven up to 75, weighs 9,500 pounds, and contains nearly its own weight of water, but only 21 pounds of steam, when under a pressure of 75 pounds per square inch, which is below its safe allowance. It stores 52,000,000 foot-pounds of energy, of which but 4 per cent. is in the steam, and this is enough to drive the boiler just about one mile into the air, with an initial velocity of nearly 600 feet per second. The common upright tubular boiler may be classed with No. 4.

Nos. 5–8 are two of the Baldwin and two of the Cooke locomotive boilers, of which drawings and weights are furnished by the builders. They are of different sizes and both freight and passenger engines. The powers are probably rated low. They range from 15 to 50 square feet in area of grate, and from 875 to 1,350 square feet of heating surface. In weight, the range is much less, running from 2½ to a little above 3 tons of water, and from 20 to 30 pounds of steam, assuming all to carry 125 pounds pressure. The boilers are seen to weigh from 2½ to 3 times as much as the water. These proportions differ considerably from those of the stationary boilers which have been already considered. The stored energy averages about 70,000,000 foot-pounds, and the heights and velocities of projection not far from 3,000 and 500 feet; although, in one case, they become nearly one mile, and 550 feet respectively. The total energy is only exceeded, among the stationary boilers, by the two-flued boiler at 150 pounds pressure.

The violence of the explosion of the locomotive is naturally most terrible, exceeding, as it does, that of ordnance fired with a charge of 150 pounds of powder of best quality, or perhaps 250 pounds of ordi-

* *The Locomotive.*, September, 1884.

nary quality fired in the usual way.* On the occasion of such an explosion which the writer was called upon to investigate, in the course of his professional practice, the engine was hauling a train of coal cars weighing about 1,000 tons. The steam had been shut off from the cylinders a few minutes before, as the train passed over the crest of an incline and started down the hill, and the throttle again opened a few moments before the explosion. The explosion killed the engineer, the fireman, and a brakeman, tore the fire-box to pieces, threw the engine from the track, turning it completely around, broke up the running parts of the machinery, and made very complete destruction of the whole engine. There was no indication, that the writer could detect, of low water; and he attributed the accident to weakening of the fire-box sheets at the lower parts of the water-legs by corrosion. The use of water-grates, the insertion of which produced some loss of strength at the fire-box, may have had something to do with it, however. The bodies of the engineer and fireman were found several hundred feet from the wreck, the former among the branches of a tree by the side of the track. This violence of projection of smaller masses would seem to indicate the concentration of the energy of the heat stored in the boiler, when converted into mechanical energy, upon the front of the boiler, and its application largely to the impulsion of adjacent bodies. The range of projection was, in one case, fully equal to the calculated range. The energy expended is here the full amount calculated.

Nos. 9 and 10 are marine boilers of the Scotch or "drum" form. These boilers have come into use by the usual process of selection, with the gradual increase of steam pressures occurring during the past generation as an accompaniment of the introduction of the compound engine and high ratios of expansion. The selected examples are designed for use in the new vessels of the U. S. Navy. The dimensions are obtained from the Navy Department, as figured by the Chief Draughtsman, Mr. George B. Whiting. The first is that designed for the *Nipsic* the second for the *Despatch*. They are of 300 and 350 horse-power, and contain, respectively, 74,000,000 and 112,000,000 of foot-pounds of available energy, or about 3,000 foot-pounds per pound of boiler, and sufficient to give a height and velocity of projection of 3,000 and above 400 feet. These boilers are worked at a lower

* The theoretical effect of good gunpowder is about 500 foot-tons per pound, according to Noble and Abel.

pressure than locomotive boilers; but the pressure is gradually and constantly increasing from decade to decade, and the amount of explosive energy carried in our modern steam vessels is thus seen to be already equal to that of our locomotives, and in some cases already considerably exceeds that which they would carry were they supplied with boilers of the locomotive type and worked at locomotive pressures. The explosion of the locomotive boiler endangers comparatively few lives and seldom does serious injury to property, outside the engine itself. The explosion of one of these marine boilers while at sea would be likely on to be destructive of many lives, if not of the vessel itself and all board.

Nos. 11 and 12 are boilers of the older types such as are still to be seen in steamboats plying upon the Hudson and other of our rivers, and in New York harbor and bay. No. 11 is a return-tubular boiler having a shell 10 feet in diameter by 23 feet long, 2 furnaces each 7½ feet deep, 8 15-inch and 2 9-inch flues, and 85 return tubes, 4½ inches by 15 feet. The boiler weighs 25 tons, contains nearly 20 tons of water and 70 pounds of steam, and at 30 pounds pressure stores 95,000,000 foot-pounds of available energy, of which 5 per cent. resides in the steam. This is enough to hoist the boiler one-third of a mile, with a velocity of projection of 330 feet per second. The second of these two boilers is of the same weight, also of about 200 horse-power, but carries a little more water and steam and stores 107,000,000 foot-pounds of energy, or enough to raise it 1,900 feet. This was a return-flue boiler, 33 feet long and having a shell 8¾ feet in diameter, flues 8½ to 15 inches in diameter, according to location. These boilers were designed, years ago, by Messrs. Fletcher & Harrison (now the W. & A. Fletcher Co.) of New York City. It was a boiler of the return-flue variety, to which that just described belongs, that exploded in the *Westfield* ferry boat, July 30th, 1871, causing the death of about 100 persons and wounding as many more. The writer was employed to investigate the case for the officials upon whom the duty was legally and technically incumbent. It was found that the cause of the explosion was the extensive corrosion of one of the girth seams of the shell. The accident occurred when the pressure was about that ordinarily carried, and considerably less than that at which the boiler had been tested but a short time before. The energy liberated was therefore about the same as would be calculated as above from the known dimensions and capacity of the boiler. The destruction of the boiler itself,

its displacement, and the destruction of that part of the boat adjacent to it, were minor effects of the accident.*

A boiler of the return-tubular class was tested to the bursting point, under steam, by Mr. F. B. Stevens, at Sandy Hook, November, 1871. The water was up to the water-line, and the energy liberated was thus the full amount calculated. As then reported by the writer,† "when a pressure of 50 pounds was reached, a report was heard which was probably caused by the breaking of one or more braces, and at 53½ pounds, the boiler was seen to explode with terrible force. The whole enclosure was obscured by the vast masses of steam liberated; the air was dotted with the flying fragments, the largest of which, the steam drum, rising to a height variously estimated at from 200 to 400 feet, fell at a distance of 450 feet from its original position. The sound of the explosion resembled that of a heavy cannon. The boiler was torn into many pieces, and comparatively few fell back upon their original position." This boiler had been tested by hydrostatic pressure, before its explosion, up to a pressure exceeding by 5½ pounds that at which the explosion occurred.

The writer subsequently calculated the amount of total energy stored in this boiler and analyzed the effects of the explosion, coming to the conclusions: ‡

"(1.) That it is very certain that the energy of this explosion, and all of its tremendous effects, were principally due to the simple expansion of a mass of steam suddenly liberated, at a moderate pressure, by the general disruption of a boiler of very uniform but feeble strength.

"(2.) That in this case, the liberation of the steam through out the mass of water contained in the boiler, and which took place by the evaporation of one pound in every thirteen of the water, and which resulted in setting free nearly 70,000 cubic feet of steam, would not seem to have taken place so promptly as greatly to intensify the effects of the explosion.

"(3.) It would seem very doubtful whether Zerah Colburn's hypothesis, which explains the violent ruptures of steam boilers by the supposition that the steam liberated from the mass of water, in cases of explosion, carries with it and violently projects against those parts of the shell immediately adjacent to the point of primary rupture,

* Journal of the Franklin Institute, September 1871, R. H. Thurston.
† Journal of the Franklin Institute, January, 1872.
‡ Journal of the Franklin Institue, Feb., 1872.

large quantities of water, which, by their impact, extend the break and increase the destructive effect, can have had an illustration in the case under consideration."

"We have no right to conclude that such an action as Colburn described may not occur in many cases of explosion; on the contrary, the simple experiment described in all text-books on natural philosophy, in which water in a closed vessel, and near the boiling point, is caused to enter into violent ebullition by the reduction pressure following the application of cold to the upper part of the vessel exhibits very plainly the probability of an action taking place such as Colburn describes." . . . . "There can hardly be a doubt that cases do occur in which the same action greatly increases the destructive effect of boiler explosions"

The more recent experiments of Mr. Lawson at Pittsburg seem to the writer to indicate very strongly, if not absolutely to prove, that the Colburn theory has a foundation in fact, and that "not only may explosions be intensified in violence, but that they may be precipitated, by the action of the stored energy of the water contained in the boiler." It is probably the conviction of the majority of engineers, familiar with steam boilers, that the danger is pretty nearly proportional to the weight of water present. The boiler exploded at Sandy Hook, as above, weighed 40,000 pounds, contained 30,000 pounds of water and 150 pounds of steam, stored over 2,500,000 of thermal units, measured from the boiling point up to 300° Fahr., equivalent to above 2,000,000,000 foot-pounds of mechanical energy, or enough to arise the whole mass more than five miles. Of this only a fraction was available, however, as shown in Table I.

The last three boilers on the list in Table II., are of a type which has come into common use only during the last 10 or 15 years. They are water-tube boilers, and all of what are popularly known as the "sectional," or "safety" class. Where a boiler is exploded, the disruption may be either general, as in some of the cases cited above, or it may be local, affecting only a limited portion of the structure. It is evident that the localization of the injury is desirable as a means of limiting the rate of discharge of the stored available energy, and thus reducing the damage resulting from the accident. It was pointed out as long ago as 1805, by the greatest engineer of this country, at that time—Col. John Stevens, of Hoboken—that the construction of boilers consisting of water tubes, principally, afforded a means of securing com-

parative safety from explosions, and a patent was issued to him by the British patent office, at that date, for a boiler resembling in its general construction the modern "safety" boiler. In the specification, communicated to the office by his son, John C. Stevens, the original of which is in the hands of the writer, Col. Stevens explains this principle of subdivision of the mass of water and of steam in boilers, as a means of insuring against destructive explosion as clearly as it has ever been explained by his recent followers. All of the latter forms of boiler belonging to this class have followed the same general plan. The writer has selected the forms here described mainly because of their being most familiar to him. He has, while preparing this paper, been engaged in directing the introduction of 250 horse-power of one type, under a very large and valuable building in New York city, where he felt unwilling to take the risk of employing a shell-boiler; he has had a boiler of another of these forms under his feet, when in his lecture-room, for more than a dozen years, where the location of a shell-boiler would have been a continual source of apprehension; and he has experimented with still another of the selected forms sufficiently to feel thoroughly at home with it, and to feel the same confidence in its safety that he has in the others. Every prudent engineer is careful to keep a shell boiler well inspected and well insured, and knows that, so cared for, the risk in their use is reduced to a very insignificant quantity; yet the writer, and probably every other engineer, finds it very satisfactory to be able to feel that any boiler that he may compelled to place under a building, or where many lives may be endangered by its explosion, is so constructed that, even were explosion to occur, it would be productive of minimum and probably small damage. The writer has not hesitated, however, where great difference of cost have entered into the case, and where the boilers could be set in a separate boiler-house, to advise the use of the shell-boiler. By proper construction, and with careful management and systematic inspection, the danger and risk are reduced to a very small amount.

The "sectional" boilers are here seen to have, for 250 horse-power each, weights ranging from about 35,000 to 55,000 pounds, to contain from 15,000 to 30,000 pounds of water and from 25 to 58 pounds of steam, to store from 110,000,000 to 230,000,000 foot-pounds of energy, equal to from 2,000 to 5,000 foot-pounds per pound of boiler. The stored available energy is thus usually less than that of any of the other stationary boilers, and not very far from the amount stored,

pound for pound, by the plain tubular boiler, the best of the older forms. It is evident that their admitted safety from destructive explosion does not come from this relation, however, but from the division of the contents into small portions, and especially from those details of construction which make it tolerably certain that any rupture shall be local. A violent explosion can only come of the general disruption of a boiler and the liberation at once of large masses of steam and water.

In the year 1872, the writer, preparing the report of a committee conducting tests of steam boilers at the exhibition of the American Institute for 1871, with the approval of the committee, wrote:*

"In this class, of which there are many different kinds in the market, the water space, and frequently the steam space, of the boiler is contained in a large number of comparatively small compartments, each of which is very strong, and the explosion of which is not likely to result in that widespread destruction of property, and that great loss of life, which so frequently follows the explosion of the older and more common forms of steam boiler.

"Your committee feel confident that the introduction of this class of steam boilers will do much toward the removal of the cause of that universal feeling of distrust which renders the presence of a steam boiler so objectionable in every locality. The difficulties in inspecting these boilers thoroughly, in regulating their action, and other faults of the class, are gradually being overcome, and the committee look forward with confidence to the time when their use will become general, to the exclusion of the older and more dangerous forms of boilers."

The writer is confident that this is still the sentiment of engineers generally, and the time to which that committee then looked forward with such interest is rapidly approaching. The figures just given and the comparisons made in this paper, may aid, somewhat, in awakening engineers to the realization of the importance of carefully considering the magnitude and the dangers of the wonderful force with which they have to deal, and to the importance of finding ways of making its use satisfactorily safe.

HOBOKEN, N. J., Oct., 1884.

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* Journal of the Franklin Institute, Feb., 1872.

GLIMPSES OF THE INTERNATIONAL ELECTRICAL EXHIBITION.

By Prof. Edwin J. Houston.

No. 2.—Dolbear's Electro-static System of Telephony.

Prominent among the numerous exhibits of telephones at the International Electrical Exhibition, was the exhibit of Prof. Amos E. Dolbear. The experiments of this gentleman in telephony were contemporaneous with those of Bell, and cover a wide field of research. Prof. Dolbear, by the introduction of several novel features, has not only greatly improved the system of magneto-electric telephony, now generally accredited to Bell, but has also invented and carried into successful, practical use, a system quite novel and distinct. We allude to his system of electro-static telephony.

The electro-static telephone of Dolbear operates on electrical principles that are radically distinct from those of the various magnetic telephones now in common use. It stands by itself as a species of telephonic apparatus, and as such possesses latent possibilities not found in magnetic telephones.

The idea of conveying articulate speech by means of electricity, like all great ideas, has not been the product of any single mind. Indeed, it appears to have occurred to many able minds long before it was so powerfully revived by the successful experiments and inventions of Bell. Nothing can illustrate the truth of this remark as forcibly as the many different claims that were brought forward during the Exhibition as to the real inventor of the telephone.

Without attempting in this paper to sketch the early inventions in telephony, it will perhaps suffice to state that the first telephone that actually transmitted intelligible, articulate speech, and that was clearly at the time of its invention claimed as able to do so, was invented by Philip Reis, in Germany, in 1860. Though considerable difference of opinion has been expressed as to the practical operation of this instrument there appears to be no doubt but that it could, and in fact did, transmit articulate speech. The success of his apparatus in accomplishing what he publicly claimed for it, would appear to be sufficient to entitle Reis to the credit of the invention.

Since the time of Reis many have claimed the telephone as their

invention. Without stopping to discuss their claims, it will suffice to say, that among them Prof. Alex. Graham Bell was one of the first to actually employ the principles laid down by Reis in his many publications on the subject, in such a manner as to permit the telephone to take the prominent commercial position it now occupies.

Prof. Dolbear was an early worker in the field of telephony. His labors appear to have been contemporaneous with those of Bell and Gray. Indeed, in the opinion of some, had he looked more carefully after his interests in the United States Patent Office, he might to-day share with Bell the credit of bringing the telephone into practical commercial use.

The early investigations of Dolbear in telephony, which we believe date from early August, 1876, resulted in the invention of the magneto-electric telephone, as distinguished from the electro-magnetic telephone; his later inventions produced his system of electro-static telephony.

In the magneto-electric telephone, the voice acting on a magnetic diaphragm moves it towards and from a coil of insulated wire wrapped around the end of a permanent magnet placed near, but not in contact with the diaphragm. These movements of the magnetized diaphragm

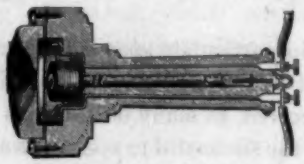

FIG. 1.—The Telephone.

towards and from the magnet pole and its insulated coil, produce electrical currents in the coil. These currents, which flow alternately in opposite directions, are caused to traverse a conducting wire and to alternately strengthen and weaken the magnetism in a similar instrument placed at the other end of the line. An increase in the strength of the magnetism causes a movement of the diaphragm of the receiving telephone towards the magnet pole; a decrease in the strength of the magnetism causes a movement of the diaphragm of the receiving telephone from the magnet pole.

Since these movements are caused by the movements of the diaphragm of the transmitting telephone towards and from the magnet pole it faces, consequent on the waves of the speakers voice falling on it, and since they produce electric currents that cause exactly similar move-

ments in the diaphragm of the receiving telephone, it follows that whatever is spoken against the transmitting telephone will be heard by an observer listening at the receiving telephone.

In order the more thoroughly to appreciate the operation of the magneto-electric telephone reference may be had to Fig. 1, in which is shown in partial longitudinal section the magneto-electric telephone receiver as generally constructed by Bell. *F*, is a straight bar magnet of steel, with its poles at its extremities. A coil of insulated wire, *H*, is placed around one end of the magnet in the position shown. Near, but not in contact with the end of the permanent magnet and its surrounding wire coil, is placed a circular plate or diaphragm of soft iron, rigidly attached at its edges, but free to move elsewhere. This diaphragm becomes magnetized by induction from the permanent magnet, and when set into vibration by the voice, produces currents of electricity in the coil *H*, that flow in one direction as the plate moves towards the coil, and in the opposite direction as it moves from it.

The manner in which these currents are utilized for the reproduction of the speaker's voice may be seen by an inspection of Fig. 2, in which

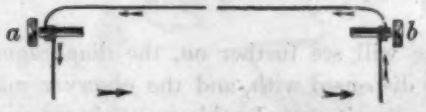

FIG. 2.—Magneto-Electric Telephone Circuit.

is shown the circuit of the ordinary magneto-electric telephone. In this case the receiving instrument is of the same construction as the transmitting instrument described in connection with Fig. 1. The circuit is represented as broken so as to convey the idea of distance.

When the diaphragm of the transmitting instrument, as for example, at *a*, moves towards the coil of insulated wire wrapped around the magnet pole, an electric current is produced which flows, we will suppose, from the coil of wire at *a*, through the ground to the other instrument, and after passing through the coil at *b*, flows over the line-wire to the other telephone. If now the direction of this current through the coil of wire in the receiving telephone is such as to increase the strength of the magnetism in the pole of the permanent magnet around which it is wrapped, its passage through the coil will be followed by a movement of the diaphragm of the receiving telephone towards its magnet pole; similarly, a movement of the diaphragm of the trans-

mitting telephone away from its magnet pole produces a current of electricity which traversing the circuit in the opposite direction, weakens the magnetism in the pole of the receiving instrument, and so permits the elasticity of its diaphragm to cause the diaphragm to move away from the magnetic pole.

The movements of the diaphragm of the transmitting telephone are therefore followed by exactly similar movements in the diaphragm of the receiving telephone. Whatever, therefore, is spoken against the diaphragm of the transmitting instrument, is reproduced by the movements of the diaphragm of the receiving instrument.

The transmitting magneto-electric telephone, therefore, is in reality a dynamo-electric machine driven by the voice of the speaker; while the receiving telephone is a dynamo-electric motor, which is so constructed as to exactly reproduce the speaker's voice.

In Dolbear's electro-static telephone the movements of the diaphragm of the receiving telephone are produced by the attractions caused by electrified bodies. The attractions of magnets are entirely done away with. The movement of the diaphragm in the opposite direction in the electro-static telephone, as in the magneto-electric telephone, is due to elasticity.

Indeed, as we will see further on, the diaphragm as well as the magnet may be dispensed with, and the observer may actually listen at the end of the line itself. In this case it is only necessary to somewhat enlarge the end of the wire.

The attractions produced when a body is electrified by friction are well known. It is attractions of this character that are utilized by Prof. Dolbear in his system of electro-static telephony.

The electricity produced by friction is, on account of its high electro-motive force, well adapted to cause the attraction of light bodies. The electricity produced by means of a voltaic cell can also cause attractions of other bodies, but owing to its comparatively low electro-motive force, such attractions are not as marked as in the case of the electricity produced by friction.

Since electricity produced by friction is not as conveniently obtained as that produced by chemical action, Prof. Dolbear employs the ordinary voltaic battery in his telephone system, and raises its electro-motive force to the requisite degree by the use of an induction coil, an instrument consisting essentially of a coil of short, coarse wire, called

the primary coil, surrounded by a coil of long, fine wire, called the secondary coil.

As is well known, when a battery current is sent into the primary circuit of an induction coil, a current is produced by induction in the secondary coil. This current, however, is produced only while the current in the primary is beginning, or is ceasing to flow, that is, while its strength is undergoing variations. As soon as the current through the primary coil is fairly established, and its strength is constant, all inductive effects in the secondary coil cease. When the battery current in the primary coil is broken or interrupted, an induced current is also produced in the secondary coil.

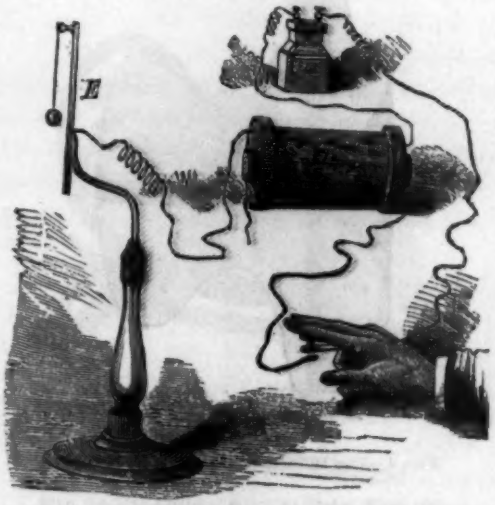

FIG. 3.—Attractions caused by a Charged Surface.

The current produced in the secondary coil by induction when the circuit of the primary coil is made or completed, flows in the opposite direction to the current in the primary; that produced in the secondary coil by the breaking of the circuit in the primary, flows in the same direction as that in the primary. Both of these induced currents possess the high electro-motive force necessary for the electro-static telephone, and are utilized by Dolbear for the reproduction of articulate speech.

When the terminals of the secondary coil are not connected, the passage of the current through the primary coil induces an electro-

motive force in the secondary that causes the potential of one terminal to be higher than that of the other, or in other words, one terminal becomes positively charged, and the other negatively charged.

If, therefore, either terminal be connected with an insulated metallic plate, such, for example, as one of the plates of an Æpinus' condenser, and a pith ball be hung before the plate in the position shown in Fig. 3, whenever the circuit of the battery is completed by depressing the key, the charge produced in the plate *E*, causes the attraction of the pith ball hung near it. Similar phenomena would be produced if the

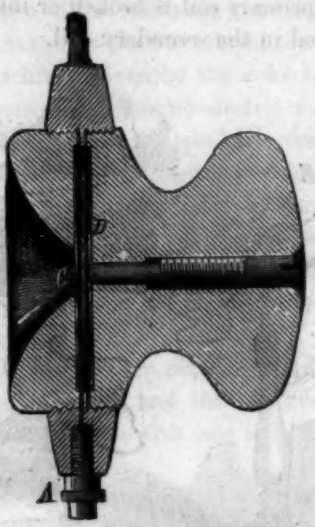

FIG. 4.—The Dolbear Electro-Static Receiver.

plate *E*, were connected with the other terminal of the secondary coil.

If, in place of the pith ball, another plate be placed near *E*, but not in electrical contact with it, and one of the plates be connected with one of the free terminals of the secondary coil, and the other plate with the other terminal, then the two plates will mutually attract each other, since one of them will receive a positive charge, and the other will receive a negative charge. If only one of the plates be free to move, the other will move toward the fixed plate, under the influence of both the charges.

Such an arrangement as that we have just described constitutes, in fact, the receiving telephone in the Dolbear system.

A form commonly given to it is shown in connection with Fig. 4.

Two metallic discs, *C*, and *D*, are mounted, as shown, so as to be near each other, but separated at their edges by some insulating substance, such, for instance, as a flange of hard rubber. The remaining portions of the plate are separated by an air space. Both plates are securely fixed at their edges, but the plate *D*, is, in addition, clamped at its middle by means of a screw. Only the plate *C*, therefore, is free to move under the influence of the electrical charges in the two plates. A suitably shaped mouth piece is placed over the plate *C*, and a conveniently shaped knob, for holding the instrument in the hand, is placed over *D*.

When the metallic discs are coated with a film of varnish or other good dielectric, they act like a Leyden jar, and may receive a permanent

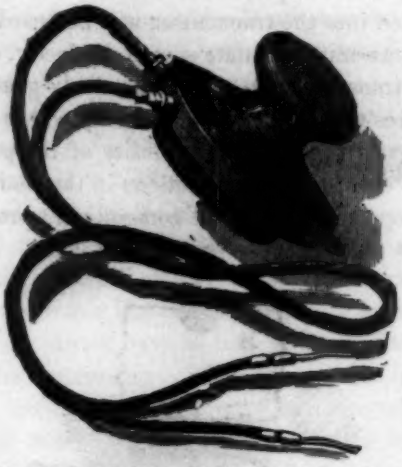

FIG. 5.—The Dolbear Electro-Static Receiver.

charge. In this condition they act like an electroscope and become exceedingly sensitive to any electrical change either of conduction or induction. Indeed, the efficiency of the electro-static telephone depends to a very great extent on this curious fact.

The receiver, therefore, is more than a mere air condenser, and depends for its efficiency upon an electrical combination thus utilized for the first time by Prof. Dolbear. When constructed and operated in this manner, the receiver becomes a transmitter, and when spoken to, transforms the vibrations of the voice into appropriate electrical vibrations, so that, from what has already been said, we may distinctly hear what is spoken, without the aid of any intermediate apparatus.

It has been found in practice that the ordinary ferrotype, photographic plates answer admirably for the purpose of an electro-static telephone receiver, since the varnish with which they are covered is superior as a dielectric, to shellac, wax, or hard rubber.

The complete receiver is shown in Fig. 5, with the separate terminals connected with each of the plates.

If one of the terminals be connected to one of the ends of the secondary coil of an induction coil, and the other end with the other terminal, then a sharp click will be heard by an observer holding the instrument to his ear, whenever the primary circuit is made or broken.

If, in place of using a key to make and break the circuit of the primary coil, an interrupter be employed capable of being operated by the voice, such, for example, as a modified Reis transmitter, then whatever is spoken into the transmitter will be heard in the receiver.

In order to transmit articulate speech distinctly, it is preferable to speak into the transmitter in a comparatively gentle tone. Under these circumstances the circuit in the primary coil is never completely broken, but the variations in the intensity of the primary current so effected, produce corresponding variations in the positive and negative charges in the opposed plates, and consequently produce, in the free plate, movements that exactly reproduce the voice.

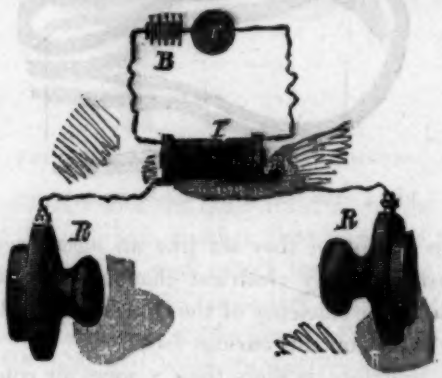

FIG. 6.—Dolbear's Singly-Connected-Plate Electro-Static Receivers.

As might be supposed, it is not necessary to connect both plates with the terminals of the induction coil. The receiver will operate if but one of the plates is so connected. In this case the other plate is connected to a metallic ring, placed on the knob, which serves as the handle of the telephone. When the hearer places his body in this manner

in electrical connection with the plate that is unconnected with the induction coil, he can hear better, because the plate can thus be the more readily oppositely electrified by induction.

It will readily be understood that in the electro-static receiving telephone it is essential that the two plates be separated by some good dielectric, or non-conducting material, since otherwise there can be no induction, and no effects of sound will be produced. Any non-conducting material between the two plates will suffice.

It is not necessary to employ the ordinary electro-static receiver, since articulate speech will be heard, if the terminals from the induction coil be suitably insulated and held to the ears of an observer, while a person is speaking into any suitable transmitter connected with the induction coil.

Any form of telephonic transmitter is suitable for use in connection with the electro-static receiver. The form employed by Prof. Dolbear is a modification of the Reis transmitter.

As we have already remarked, a high electro-motive force is necessary for the successful use of the electro-static telephone receiver. For this reason the transmitter is always used in connection with an induction coil. In order to insure the requisite electro-motive force, the secondary coil in the induction coil is made of a comparatively high resistance, such, for example, as four or five thousand ohms.

It is on account of this higher electro-motive force, that resistances inserted in the line circuit have so little effect in diminishing the efficient action of the instrument. Therefore, by the use of the electro-static telephone, articulate speech may be successfully transmitted through distances much greater than is possible with the magneto-electric telephone.

Indeed, it is not resistance that is to be avoided in the electro-static telephone but an increase in the electro-static capacity of the circuit. Now, since the electro-static capacity decreases with the decrease in the diameter of the wire, and since a high resistance is of no particular disadvantage, the finer the wire the more perfectly is the disadvantage due to the electro-static capacity of the wire obviated. If, therefore, a sufficiently fine wire could be stretched under the Atlantic, trans-Atlantic telephony would be rendered quite feasible by the use of Prof. Dolbear's inventions.

In Fig. 7, for which, in common with Figs. 3, 4, 5 and 6, the author is indebted to the *Scientific American*, of June 18, 1881, is shown the complete Dolbear telephone system.

The induction coil, *I*, is connected with the battery, *B*, as shown. The transmitter, *T*, is placed in the circuit of the battery and the primary wire of the induction coil. The receiver, *R*, is connected, as shown, to the terminals of the secondary coil of the induction coil, *I*. Similar instruments are placed at the other end of the line. When a person wishes to talk into the transmitter, a key, *b*, readily permits him to cut out his receiving instruments.

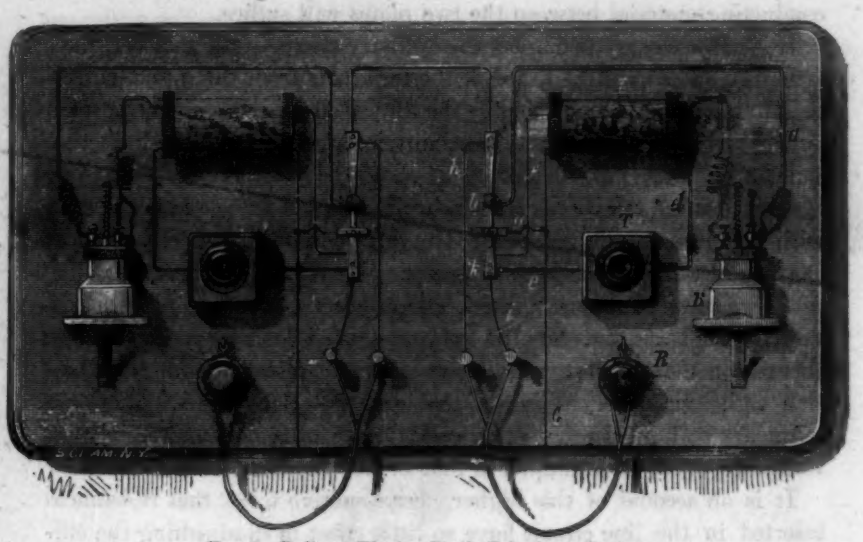

FIG. 7.—Dolbear Electro-Static Telephone System.

From the preceding description it will appear that the electro-static telephone of Dolbear forms a species of instrument quite distinct from other telephones. Although it follows Reis, in that it employs the voice of the speaker to vary the amount of battery current that traverses the primary circuit of an induction coil, yet it differs from Reis, and all who have followed him, in that it takes the electrical current so modified and utilizes it directly for the reproduction of the original speech by the attractions caused by its differences of potential. In this respect, as will be observed, it differs radically from the Bell instrument, in which the electrical current, when modified by the voice, is not directly utilized for the reproduction of the original speech, but for the purpose causing variations in the magnetism of an electro-magnet, these variations in the magnetism being made to reproduce the original speech by their attractions of a magnetized diaphragm.

The electro-static telephone possesses some advantages not found in

other telephones. One of the most important of these advantages is its marked freedom from the effects of induction currents from neighboring conductors. The electro-static telephone owes this peculiarity to the high electro-motive force it necessarily employs in order to obtain the requisite movements of the plate of the receiving instrument. The electro-motive force of the currents ordinarily induced in telephones is too low to produce any noticeable effects in the electro-static instrument. There is, therefore, a marked absence of the annoying spluttering and frying sounds so common in magneto-electric telephones whose circuits extend near and parallel to other conductors. For similar reasons the electro-static telephone is much less affected by earth currents than the ordinary magneto-electric telephone.

Prof. Dolbear has invented a new form of transmitter, which he calls the battery transmitter. It consists essentially of two battery plates, separated by an electrolytic liquid. When the voice of the speaker is directed against one of the plates, it is moved thereby towards and from the other plate, and thus, decreasing and increasing the internal resistance of the battery, causes corresponding variations in the current strength produced. The battery transmitter has been found in practice to give excellent results.

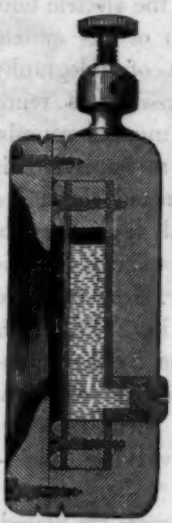

FIG. 8.—Dolbear's battery transmitter.

One form of battery transmitter is shown in Fig. 8, in which *I*, represents a plate of any suitable metal, such, for example, as zinc, while opposite it is placed a plate of carbon. These plates, when properly insulated from each other, will form a shallow cell when filled with a suitable electrolytic liquid, as shown.

If now a speaker talks into the mouth-piece, the plate *I*, is moved by the sound waves towards and from the carbon plate. The variations thus produced in the distance between the two battery plates cause corresponding variations in the strength of the current passing through the battery, in consequence of the variations in the resistance of the cells.

CENTRAL HIGH SCHOOL,
PHILADELPHIA, November 3d, 1884.

[NOTE.—The cuts necessary for the illustration of the remainder of this article could not be obtained in time for the present issue of the JOURNAL. The remainder of the article on Dolbear's researches will, therefore, appear in a subsequent number of the JOURNAL.—EDS., J. F. I.]

GLIMPSES OF THE INTERNATIONAL ELECTRICAL EXHIBITION.

By Prof. Edwin J. Houston.

No. 3.—Gray's Telephonic Inventions.

Among the names of the distinguished scientific men who have aided in the production of the speaking or articulating electric telephone, that of Elisha Gray, of Chicago, occupies no mean position. Like most of those who aided in the invention of this marvelous instrument, the work of Mr. Gray leading towards his part of this invention dated from a time several years prior to this production of a working instrument.

The part played by Mr. Gray in the invention of the electric telephone was the natural outgrowth of his conception of his system of multiplex-harmonic telegraphy. In this system of telegraphy by means of which the multiple transmission of messages is rendered electrically possible, all the characteristics of musical sounds, the pitch, the intensity and the quality, are caused to impress their peculiarities on an electrical current, which is transmitted through a conducting wire, and is caused, by suitable electrical appliances, to reproduce, at the receiving end of the line, the peculiarities of the sounds impressed on it at the transmitting end. Mr. Gray invented this system of multiple-electric transmission early in 1874. His method consists substantially in sending into the line, by the vibration of tuning-forks, or tuned reeds, separate series of electrical impulses, that vary both in their strength and in their rapidity. There is thus charged on the line electrical impulses varying considerably both in their rapidity and in their strength.

At the distant end of the line a series of electro-magnets are placed, the armatures of which are rigidly attached at one of their ends to one of the poles, the other end being free to vibrate towards and from the free pole. If then the end of the line be connected to a number of different electro-magnetic receivers, the rate of vibration of which exactly corresponds with the rate at which the separate series of electrical impulses were sent into the line, each of the receivers will be actuated by those electrical impulses, that correspond in frequency to the frequency with which it swings, and by those impulses alone.

A number of independent messages, therefore, can thus be sent over the line without in any respect interfering with one another.

Mr. Gray carried on an extensive series of experiments with his multiple-telegraph apparatus, the natural outgrowth of which resulted in his filing in the United States Patent Office, on the 14th of February, 1876, a caveat for "a new art of transmitting vocal sounds telegraphically." In this caveat he specifically states, "It is the object of my invention to transmit the tones of the human voice through a telegraphic circuit, and reproduce them at the receiving end of the line, so that actual conversation can be carried on by persons long distances apart."

Singularly enough, this specification was filed in the United States Patent Office on the same day that Alexander Graham Bell filed his specification for "a method of, and apparatus for, transmitting two or

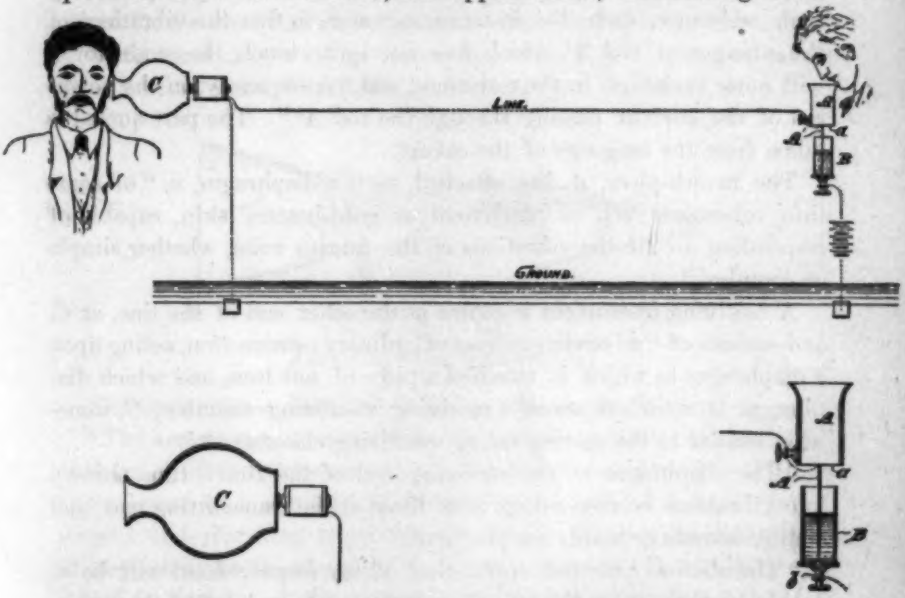

FIG. 1.—Gray's first articulating telephone (caveat design).

more telegraphic signals simultaneously along a single wire by the employment of transmitting instruments, each of which occasions a succession of electrical impulses differing in rate from the others; and of receiving instruments, each tuned to a pitch at which it will be put into vibration to produce its fundamental note by one only of the

transmitting instruments." This is the specification on which Bell rests his claims for the invention of his first articulating telephone.

Thus it will be seen that by a remarkable coincidence these two applications for government protection for the invention of telephones were not only filed on the same day, but were also the direct outgrowth of two very similar systems of multiple electric telegraphy.

In Fig. 1, is shown the instrument as figured in Mr. Gray's caveat of February 14, 1876.

In this early form of instrument the transmitter is shown at *A*. The instrument, therefore, belongs to that class of telephones in which the voice of the speaker is caused to vary an electrical current by producing variations in the resistance of its circuit.

In Fig. 1, a battery, grounded at one end as shown, has its other terminal connected to the vessel *B*, "filled with some liquid possessing high resistance, such, for instance, as water, so that the vibrations of the plunger or rod A^1, which does not quite touch the conductor *b*, will cause variations in the resistance, and, consequently, in the potential of the current passing through the rod A^1." The part quoted is taken from the language of the caveat.

The mouth-piece, *A*, has attached to it a diaphragm, *a*, "of some thin substance, such as parchment or gold-beaters' skin, capable of responding to all the vibrations of the human voice, whether simple or complex."

A receiving instrument is shown at the other end of the line, at *C*, and consists of "an electro-magnet of ordinary construction, acting upon a diaphragm to which is attached a piece of soft iron, and which diaphragm is stretched across a receiving vocalizing chamber, *C*, somewhat similar to the corresponding vocalizing chamber *A*."

"The diaphragm at the receiving end of the line is thus thrown into vibrations corresponding with those at the transmitting end, and audible sounds or words are produced."

"The obvious practical application of my improvement will be to enable persons at a distance to converse with each other through a telegraphic circuit, just as they now do in each other's presence, or through a speaking tube.

"I claim as my invention the art of transmitting vocal sounds or conversations telegraphically through an electric circuit."

The invention thus embodied by Gray in his caveat of 1876, he claims, was conceived by him at a much earlier date, but owing to press of other electrical work, was not embodied in an actual written

description until shortly before the time of filing the caveat. The idea of the invention was suggested to him by the string telephone, and an examination of Fig. 1, will show that he has, to a certain extent, copied this instrument electrically.

Unfortunately for Gray, he did not have a working model of his telephone completed until after Bell had modified the instrument described in his application for letters-patent filed on the same day as that on which Gray deposited his caveat in the Patent Office. We say unfortunately, since Gray's first instrument would transmit intelligible, articulate speech, while Bell's original instrument would not.

In order the better to compare the invention set forth in the caveat of Gray with that of Bell, we will annex a short description of that part of the apparatus described in Bell's application of February 14, 1876, the application that is claimed to cover the invention of a telephone for the electrical transmission of articulate speech. This form of instrument is shown in connection with Fig. 2, which is taken directly from figure 7 of Bell's specification.

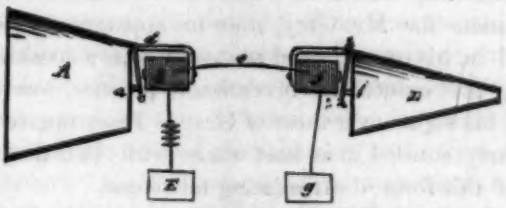

Fig. 2.—Bell's original instrument.

This apparatus is described in his specification as follows, viz.:

"The armature *c*, is fastened loosely by one extremity to the uncovered leg *d*, of the electro-magnet *b*, and its other extremity is attached to the centre of a stretched membrane, *a*. A cone, *A*, is used to converge sound-vibrations upon the membrane. When a sound is uttered in the cone the membrane *a*, is set in vibration, the armature *c*, is forced to partake of the motion, and thus electrical undulations are created upon the circuit *E*, *b*, *c*, *f*, *g*. These undulations are similar in form to the air vibrations caused by the sound; that is, they are represented graphically by similar curves. The undulatory current passing through the electro-magnet *f*, influences its armature *h*, to copy the motion of the armature *c*. A similar sound to that uttered into *A*, is then heard to proceed from *I*."

This instrument does not appear to have been capable of transmit-

ting intelligible, articulate speech, in the form in which it is figured and described in Bell's early specification. The best results he was able to obtain from it were faint sounds, heard by his assistant, but not verified by Bell. Or, quoting the language employed by Bell in a lecture delivered before the Society of Telegraph Engineers, October 31, 1877: "The results were unsatisfactory and discouraging. My friend, Mr. Thomas A. Watson, who assisted me in this first experiment, declared that he heard a faint sound proceed from the telephone at his end of the circuit, but I was unable to verify his assertion. After many experiments attended by the same only partially successful results, I determined to reduce the size and weight of the spring as much as possible. For this purpose I glued a piece of clock spring, about the size and shape of my thumb nail, firmly to the centre of the diaphragm, and had a similar instrument at the other end; we were then enabled to obtain distinctly audible effects."

Before Gray had a working model made in accordance with his caveat, Bell modified his apparatus in the manner above described, and had successfully transmitted intelligible, articulate speech. This was unfortunate for Mr. Gray, since his apparatus, when constructed as described in his caveat, acted successfully as a speaking telephone. Bell, having first reduced his invention to practice, was successful in establishing his rights over those of Gray. From the record, however, Gray is clearly entitled to at least share with Bell the honor for the invention of this form of articulating telephone.

The modified form of Bell receiver, by means of which he obtained his first satisfactory, intelligible, articulate speech, is similar to that shown in (section) Fig. 3.

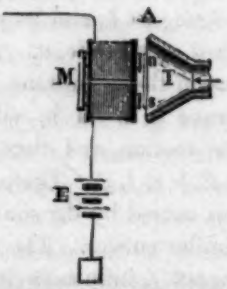

FIG. 3.—Bell's modified telephone receiver (section).

This receiver consists, as shown, of an electro-magnet *M*, opposite the poles of which is a tightly-stretched membrane which closes a

mouth-piece *T*. A piece of watch spring in the form of a permanent magnet, *n*, *s*, is rigidly attached to the middle of the membrane. This modified form of receiver is shown in elevation in Fig. 4.

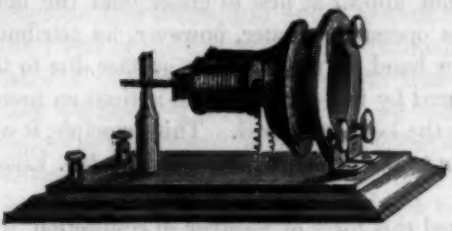

FIG. 4.—Bell's modified receiver (elevation).

Continuing his experiments as to the most favorable conditions for the proper working of his telephone, Bell made numerous experiments as to the influence produced by variations in the size of the different parts. Among other things, he gradually increased the size of the magnet fastened to the diaphragm of gold-beater's skin, until at last he he entirely replaced the gold-beater's skin diaphragm by one of iron, and thus vastly improved the efficiency of his instrument.

While experimenting on the simultaneous multiple transmission of various tones electrically, Gray made several forms of receiving instruments for causing such tones to be heard at the distant end of the line. One of these, which was devised some time before the form shown in the caveat of February 14, 1876, was suggested by a sound heard from a bath tub, to the metallic lining of which one of the terminals of the secondary wire was attached. This sound was heard when the dry hand, grasping the other terminal, was slid over the lining. Gray experimented at considerable length on this curious observation, and soon found that a receiver of this character was able to reproduce sounds of varying pitch, so that a tune played at the distant end of the line was distinctly reproduced by the receiver.

In order to readily obtain the continuous sliding motion necessary in this form of receiver, Mr. Gray mounted a thin, cylindrical, resonant box of wood on a horizontal axis; on the cylindrical surface of the box was placed a slightly convex, metal cap. The metal cap was connected to the ground by means of a wire. When the end of the line was held in the hand and the fingers were pressed against the metal cap, musical sounds made at the distant end of the line were distinctly heard when the cylinder was revolved. When the current passing is sufficiently great,

these sounds are readily heard at some distance from the receiver. Within certain limits they increase in loudness when the crank is turned more rapidly.

Gray did not appear at first to understand the manner in which these receivers operated. Later, however, he attributed them to the slipping of the hand on the metallic surface due to the variations in friction produced by the current. He noticed an increase in the friction whenever the key was closed. This principle, it will be observed, is quite similar to the principle employed by Mr. Edison in his motograph.

Gray patented this form of receiver in connection with a telephonic

FIG. 5—Gray's Telephone Receiver.

transmitter that was able to transmit articulate speech, in 1878. He obtained the necessary electro-motive force of the electrical currents requisite for the successful operation of the receiver by the use of an induction coil. He points out in this patent the fact that other animal tissues may be employed in the place of the fingers of the hand. In this application the receiver is figured as a highly polished metallic disc of thin sheet metal, mounted on a resonant box or case, provided with a shaft so as to be readily revolved.

An exceedingly simple, yet quite efficient receiver is shown in Fig. 5. In this form, an iron vessel, supported as shown, is firmly fixed in

an upright position by one of its edges. An electro-magnet, separately mounted on the same base, has its poles near, but not in contact with the bottom of the pan. Under these circumstances the bottom of the pan acts as a magnetic diaphragm, and emits musical or other sounds, uttered at the other end of the line, with great distinctness.

The resemblance of this form of receiver with that now employed in the articulating telephone is too evident to need comment. It will speak quite plainly when placed in connection with any form of articulating transmitter, such for example as that figured in the Gray caveat, or with a Reis transmitter. Indeed two such instruments placed at the extremities of a circuit in which is included a battery, form a complete telephonic system, since one of them can be used as a transmitter, while the other will act as a receiver.

Although these receiving instruments were not used by Gray to receive articulate speech prior to the actual use by Bell of his form of articulating telephone, yet they are of interest when taken in connection with the actual position that Gray occupied as regards the articulating telephone as exhibited by the description contained in his caveat of February 14, 1876. In that paper he clearly expresses the objects of his invention as being means for varying an electric current by the human voice for the purpose of throwing on a telegraph line such variations as will, when suitably received at the distant end of the line, reproduce the voice. He figures a form of transmitting instrument that will so permit the voice to vary the current of a voltaic battery and a form of receiver that will act in connection therewith. He is operating with a current that is greatly varied, and contrives for its reception a receiver that is capable of responding to a wide range of variations. Since then the receiver shown in Fig. 5, was devised for exactly the same purpose, he is, it would seem, be entitled to use it to replace the receiver shown in his caveat already referred to.

On the 29th of October, 1877, Gray filed a number of applications for letters patent, viz.: one for the "art of transmitting vocal sounds telegraphically," one for "certain new and useful improvements in apparatus for transmitting vocal sounds telegraphically," and one for "certain new and useful improvements in electric telephony." In the latter application he figures substantially the telephone receiver, which is shown in connection with Fig. 5. This he styles his "concave diaphragm receiver," for speaking telephones. His application shows

similar instruments at each end of the line, for receiving and transmitting instruments respectively.

Gray has added a number of important features to the articulating telephone as it is to-day commercially employed. He took out a number of patents in 1878. Among other instruments he devised a method by means of which the weakening effects on the electric currents transmitting articulate speech, due to their passage through a number of instruments, calls, etc., placed in series in the main line, were decreased. This method consisted essentially in the use of condensers.

In the same year he invented a contrivance by means of which all sounds not transmitted through the line wire are excluded from the observer's ear. This he effected by mounting two telephones on a common support so that they could readily be simultaneously applied to both ears of the person receiving the message. The two telephones were mounted on rocking bearings so as readily to adapt themselves to the ear of the listener. At the same time the handle of the common support, on which they were mounted, was made so as to readily be grasped in one hand, thus leaving the other hand free to hold an ordinary transmitting instrument to the mouth, when it was desired to send a message.

FIG. 6.—Gray's Bi-polar Telephone.

Gray invented his bi-polar telephone, shown in Fig. 6, in 1878. In this instrument, as the name indicates, there are two magnet poles, each of which is caused to act on a separate metallic diaphragm, inclined at such an angle with respect to each other as to permit the use of a single

mouth-piece placed between them. A permanent magnet, U-shaped, serving as the handle of the instrument, has two electro-magnets secured to its two poles. The soft iron cores of these magnets are provided with the usual coils of insulated wire. The cores are attached to the permanent magnet by securing them into ends thereof, so that they are thus readily adjusted with respect to the iron diaphragms, of the usual construction placed, opposite them.

In the same year Gray extended the idea contained in his bi-polar telephone and constructed a device which he termed his "duplex-bi-polar telephone." The object of this instrument is to increase the volume and clearness of the sound. This he endeavored to secure by the combination with a common mouth-piece, of a series of diaphragms with their corresponding magnets "arranged in pairs on the outer, opposite sides of the poles of a permanent magnet and in a reverse order relatively thereto, in such a manner that the secondary diaphragms, and the magnet of each pole will be actuated directly from or by its primary diaphragm."

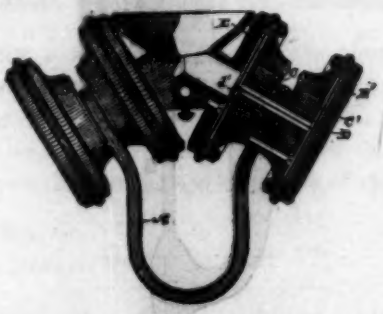

FIG. 7.—Gray's Duplex-Bi-polar Telephone.

Gray has produced a number of modifications of his bi-polar instrument. Besides the duplex bi-polar telephone above described, he patented, in 1878, another modification intended to increase the electro-motive force of the generated current, and to obtain an increased volume and clearness of the sound produced. In one form he shows a bi-polar telephone "with its diaphragms and electro-magnets duplicated, and arranged in reverse order on each side of the poles of its permanent magnet. The soft iron core of the electro-magnet is made tubular. Through this core a light rod of wood or other non-magnetic material passes. The ends of this rod are rigidly attached to the centres of both diaphragms, so that the move-

ment of either of the diaphragms produces corresponding movements in the other diaphragm. By this arrangement the inventor is enabled to vibrate two diaphragms before two electro-magnets, both of which receive their magnetic charge from the same pole of the permanent magnet. The other pole of the permanent magnet has similar apparatus connected with it, so that the inventor thus obtains the current produced by the vibrations of four separate diaphragms.

This form of telephone is shown in Fig. 7. The U-shaped steel magnet is seen at *A*. The tubular soft iron core, *D*, is provided with helices *C*, C^1, and diaphragms *E*, E^1. The rod d^1, intended to carry the motion of the diaphragm nearest the mouth to the other diaphragm, is connected to the two diaphragms as shown. On the left hand side of the drawing similar parts are shown in elevation.

In Fig. 8 is shown Gray's electro-magnetic telephone. This instru-

FIG. 8.—Gray's Electro-magnetic Telephone (section).

ment consists of a handle, *H*, of iron or steel, furnished with a soft iron core, *C*, connected by means of a screw, with one end of *H* in the manner shown. This core is wrapped with a coil of wire of comparatively low resistance that is included in the circuit of a voltaic battery of two or three cells. Opposite to the core of this magnet, and mounted thereon in the same plane, but separated therefrom by some non-magnetic material, is placed a second electro-magnet. The core of this magnet is made of a slotted tube of soft iron. The coil of wire wrapped thereon is made of a much higher resistance than the coil in the first magnet. A stiff spring-plate, *B*, of iron or steel is

secured at one end to the handle, *H*, and at the other end is perforated so as to permit the magnet core, *C*, and its coil to pass through it. This metallic plate is securely attached at its upper edge to the edges of the magnetic diaphragm. In this manner, as will be seen, the

FIG. 9.—Gray's Electro-magnetic Telephone (elevation).

opposite poles of the magnet are brought into close proximity with each other, and their magnetic effects greatly increased.

The idea of thus connecting the diaphragm with the opposite pole of the magnet has been employed in a number of different telephones.

In Fig. 9 is shown the elevation of this form of speaking telephone.

CENTRAL HIGH SCHOOL,
Philadelphia, Nov. 15, 1884.

ABNORMAL FLOWERS.—A young botanist found, on the borders of a forest, near Brussels, a poppy in which the four petals, by the union of their opposite edges, had become tubular, each presenting the appearance of a monopetalous infundibuliform corolla, giving the flower a strange but somewhat elegant appearance. Transformations of leaves into tubular or vermiform organs are normal in some plants, such as the nepenthe, the sarracenia, etc., and accidental transformations are not uncommon. In the vernation of the poppy each petal is folded upon itself, in such a way that its lateral borders coincide throughout their whole length. It is not then so astonishing that they should sometimes unite, as that they unite so rarely. There is one cultivated variety of poppy, the *papaver bracteatum*, in which the petals are joined at their borders, so that the flower presents the appearance of a large cup.—*La Nature*, May 24, 1884. C.

THE EARTH'S ELLIPTICITY.

By L. D'AURIA.

In the October number of the JOURNAL OF THE FRANKLIN INSTITUTE, Prof. Chase states that in my paper of August (this JOURNAL) I have introduced some of the elements omitted in my former paper on the Ellipticity of Planets, and takes the credit to have called my attention to it by his criticism. This statement is incorrect, for I have treated the same general equation with the same elements as before in the paper quoted, only have amended an error which occurred in assigning the limits to certain terms contained in such equation.

Moreover, the professor declares untenable the hypothesis which I was forced to admit, viz., that the earth's ellipticity may have been formed and retained at a time when gravity at the poles was almost equal to gravity at the equator, and that from such time gravity at the poles has been increased over that at the equator by some unknown cause, without, however, being able to affect the already formed ellipticity, on account of the earth's rigidity.

The only part of this hypothesis which may seem hard to admit is how, without any change of form in the earth, the ratio of gravity at the poles to that at the equator could undergo any variation whatever. In answer to this I would respectfully say that it is very doubtful whether any scientific man is prepared to tell us what variation the specific gravity of bodies at the earth's surface would undergo were the earth deprived of its magnetic properties. Could it not be that the increase of the above ratio from 1 to 1·00167, as required by my analysis, is due to magnetism?

The professor will be surprised, perhaps, to learn that in the "Phil. Trans." for 1847 there is a memoir, by Hearn, entitled: "On the cause of the discrepancies observed by Mr. Baily with the Cavendish apparatus for determining the mean density of the Earth," where these discrepancies are attributed to the influence of magnetism.

Prof. Chase tests my analysis by his harmonic theory of the universe. According to this theory, he insists that the ratio

$$(v_2 \div v_1)^2,$$

must be the measure of the earth's oblateness, and seems to be unaware of the fact that such ratio is simply that of centrifugal force to attrac-

tion at the equator. In fact, $v_1 = \sqrt{gr}$, where r is the equatorial radius, g gravity at the equator, and v_2 is the actual velocity of rotation of the earth at the equator. Hence

$$(v_2 \div v_1)^2 = \frac{v_2^2}{gr} = \frac{v_2^2}{r} \div g;$$

and since $\frac{v_2^2}{r}$ represents centrifugal force at the equator, it follows that the professor, without knowing it, insists that the oblateness and the ratio of centrifugal force to attraction at the equator are one and the same thing.

By the same harmonic theory, Prof. Chase, in this JOURNAL for May, 1884, computes the sun's distance, and substantially puts it as follows:

$$\text{Sun's dist.} = \tfrac{5}{2} \times \tfrac{3}{2} \times 31{,}558{,}149 \times \sqrt{gr} \div 2\pi;$$

where 31,558,149 is the period of revolution of the earth around the sun expressed in seconds. Since g is directly proportional to r, we can put

$$g = r \times \text{constant} = Cr;$$

and consequently it follows that

$$\text{Sun's dist.} = r \times \text{constant};$$

for the fractions $\frac{5}{2}$ and $\frac{3}{2}$ remain the same independently of r.

If we suppose the earth to be condensing into a smaller volume; it should be expected that by such process we would be brought nearer to the sun in proportion as the radius of the earth diminishes. Is Prof. Chase aware that such absurdities are sheltered by his new science?

WEIGHT OF DROPS.—Boymond has lately published an interesting notice upon the weight of drops. It is well known that the weight depends upon the exterior diameter of the tube; the interior diameter having no influence except upon the velocity of flow, the nature of the liquid determines the weight, whatever may be the proportion of dissolved material that it contains. Boymond used a dropper of three millimetres diameter and determined the weights by an extremely sensitive balance. The mean of his results gave, in a gramme of distilled water, 20 drops; alcohol of 90°, 61 drops; alcohol of 60°, 52 drops; alcoholic tinctures from 60° to 90°, 53 to 61 drops; etherial tincture, 82 drops; a fatty oil, about 48 drops; a volatile oil, about 50 drops; an aqueous solution, whether diluted or saturated, 20 drops; a medicinal wine, 33 to 35 drops; laudanum, about 33 to 35 drops.—*La. Nature*, April 12, 1884. C.

THE EARTH'S ELLIPTICITY.

By L. D'AURIA.

In the October number of the JOURNAL OF THE FRANKLIN INSTITUTE, Prof. Chase states that in my paper of August (this JOURNAL) I have introduced some of the elements omitted in my former paper on the Ellipticity of Planets, and takes the credit to have called my attention to it by his criticism. This statement is incorrect, for I have treated the same general equation with the same elements as before in the paper quoted, only have amended an error which occurred in assigning the limits to certain terms contained in such equation.

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STANDARD SIZES FOR HEXAGON BOLT HEADS AND NUTS.

[In *Mechanics*, November, 1884, a communication on the above caption from Mr. C. E. Simonds, East Cambridge, Mass., was published. This we reproduce with some remarks by Mr. Coleman Sellers, Professor of Mechanics in the Institute, who was a member of the Committee of the Franklin Institute that reported on this subject December 15th, 1864.]

"The advantages of a system by which certain classes of machine-work can be constructed and placed upon the market are of untold value so long as the product is constructed according to the rule given. Adopting a rule is one thing, but universally working to it is another matter. On December 15, 1864, a system of bolt heads and nuts, as well as screw threads, was recommended and adopted by a committee of the Franklin Institute of Philadelphia, and adopted by the United States Government in May, 1868. It is well, perhaps, to state that this system is known as the Sellers' or Franklin Institute, likewise the United States' standard. The sizes or dimensions of the width of the parallel sizes of a hexagon bolt head and nut are $1\frac{1}{2}$ times the diameter of the bolt plus $\frac{1}{8}$ inch when the nut or bolt head are in the rough state; thus it will be seen by the rule that a nut or bolt head for a 1-inch bolt should measure $1\frac{5}{8}$ inches. For a finished hexagon bolt head and nut the rule is $1\frac{1}{2}$ times the diameter of the bolt plus $\frac{1}{16}$ inch, and the nut and bolt head should thus measure $1\frac{9}{16}$ inches.

"The writer, some time ago, furnished drawings for a complete set of wrenches of the drop-forged system, and the sizes given were for bolts from $\frac{1}{4}$ inch to 6 inches inclusive. A large number of the wrenches were milled exact to size, case-hardened and placed upon the market, and the undertaking brought to light the astonishing fact that of all the manufacturers of hexagon bolt heads and nuts in the United States not one can be found who manufacture nuts and bolt heads according to the rule as given by the Franklin Institute. Messrs. Hoopes & Townsend, of Philadelphia, in their catalogue state that the nuts on pages 20 and 21 are United States' standard sizes and have been adopted as standard by several of the most prominent railroads. Pages 20 and 21 gives sizes of bolts and nuts from $\frac{1}{4}$ inch to 3 inches, the list including cold-punched, chamfered and trimmed nuts; also cold-punched nuts for cars and unfinished work. It is to be borne in mind that the manufacturers state that they are United States' standard

sizes. If the rule of $1\frac{1}{2}$ times the diameter of the bolt plus $\frac{1}{16}$ inch be correct, how is it that Messrs. Hoopes & Townsend, as well as all of the manufacturers of nuts and bolts, make their product $\frac{1}{16}$ inch larger, and distinctly state that the thread and outside of each bolt head and nut are made to an accurate gauge and to the standard adopted by the United States Government? What are mechanics to understand by these statements? Do goods manufactured $\frac{1}{16}$ inch over size mean that they are to be classed with articles manufactured $\frac{1}{16}$ inch less in size, which is the true size.

"Page 42 of their catalogue gives proportions for United States standard screw threads and nuts. Taking from their table a bolt of 1-inch diameter, it is shown that the width of the parallel sides of a nut are $1\frac{1}{8}$ inches; according to the Sellers or Franklin Institute system it should be $1\frac{9}{16}$ inches. Take, again, the list of sizes as given on page 7, which, by the way, are stated to be standard sizes of heads for bolts—it will be noticed that the word standard is affixed to everything on this page—$1\frac{9}{16}$ inches is given for the size of nut for a 1-inch bolt. This is correct. What does this mean? Perhaps Messrs. Hoopes & Townsend will explain what the word standard means. Haswell's pocket edition for mechanics and engineers for 1870 gives on page 123 a list of sizes of nuts and bolts from $\frac{1}{4}$ inch to 6 inches inclusive. This list gives as a rule $1\frac{1}{2}$ times the diameter of the bolt for the width of the nut, and hence by this rule we have another size of nut. On the next page Mr. Haswell gives the sizes of screw threads, bolt heads and nuts as per rule of the Franklin Institute. Why Mr. Haswell gives two sizes of nuts for the same bolt is a mystery to the writer. The sizes thus shown in this edition are $1\frac{1}{2}$ and $1\frac{9}{16}$ inches for a bolt of 1 inch diameter. In the revised edition for 1884, page 157 gives $1\frac{1}{2}$ times the diameter of the bolt for the width of the head, and $1\frac{1}{2}$ times the diameter plus $\frac{1}{8}$ inch as the width of the parallel sides of a hexagon nut. Rather poor information to be found in a revised edition. Mr. Trautwine in the revised edition of his pocket-book gives as a rule $1\frac{1}{2}$ times the diameter of the bolt for the width of the parallel sides of a hexagon bolt head and nut, and he says that some machinists add $\frac{1}{8}$ inch to this for all diameters of bolts. The word *some* is very amusing, taken as it is from the pages of a work devoted to the interests of mechanics.

"In *Mechanics* for March 18, 1882, a correspondent asks for information regarding the sizes of standard bolt heads and nuts of the Frank-

lin Institute system, in which he feels sure that it would be conferring a great favor upon many readers, and would at the same time enlighten many workmen who are not posted upon the subject. The sizes, as well as the information thus given, are taken from the revised edition of Mr. Nystrom's pocket-book, and it is stated that the sizes are those of the Franklin Institute system, which, by the way, is not the case, inasmuch as the sizes given are $\frac{1}{16}$ inch over size. At the end of the article it is stated that the workman should bear in mind that these dimensions are finished sizes, and are intended for use on either black or bright work; and, furthermore, that the same size wrench will fit either finished or unfinished bolt heads and nuts. The *Scientific American Supplement*, No. 443, page 7072, for June 28, 1884, contains the best and only correct table ever published. To the railroad master-mechanic, master car-builders and mechanics in general the questions arise, Is it possible to ever correct the error which has existed for a period of over 20 years? Is it not best to drop the word standard, and forget that there was ever such a word? It looks something like counting chickens before they are hatched. We have got the word standard, but where are we to find the nuts or the manufacturers who know what the standard is and who work to it?"—*C. E. Simonds, in Mechanics.*

REMARKS ON THE FOREGOING:

The Franklin Institute standard of *bolt threads* is the same as that of the United States Government, as fixed by the board under Mr. Isherwood, then Chief of the Bureau of Steam Engineering, May 15, 1868. In regard to the size of the heads of bolts and also the size of nuts the Franklin Institute standard *is not* the same as that adopted by the United States Board and now called the United States standard. Mr. Simonds correctly states the Institute standard for finished bolt heads and nuts to measure, for the width between the parallel sides of hexagon nuts, once and one-half the diameter of the bolt plus one-sixteenth of an inch, That is to say, rough bolts made one and one-half plus *one-eighth* of an inch can be planed or dressed to the finished size, there being sufficient stock for that purpose. The Government Board decided that all bolt heads and nuts should be made the same size, whether black (that is rough) or finished, so that the same wrench could be used on either. Unfortunately they adopted as the size of the finished bolt head and nut the rough size, as indicated by the

Franklin Institute committee. Messrs. Hoopes & Townsend are hence quite correct in calling their product the United States standard. Accepting the fact that there has thus come to be a discrepancy between the standard recommended by the Institute and the United States, it may be well to say a few words about the principle involved. I may say that there are many very large concerns, which, having adopted the Franklin Institute standard of bolt heads and nuts, have come, since the introduction of the improved methods of making forgings and cold pressed nuts, to call all nuts and bolt heads *finished* that are made to gauge either in the smith shop or in the machine shop. It would be doing injustice to the very good nuts, for instance, made by Messrs Hoopes & Townsend, to call their cold pressed nuts, sized by passing through gauged dies, "unfinished" or "rough" nuts. They are as accurate to size as the nuts finished and polished in many machine shops. It is no very easy matter, nor is it wise, for those who have adopted the smaller size of the Franklin Institute, to revert to the larger size recommended by the Government Board. Machines having bosses raised on the patterns for the bolt heads and nuts, will require such bosses to be enlarged for the larger size. Bolts placed near to flanges, in corners or near edges, will have to be moved away from the flange or farther from the corner to allow room for the use of wrench. Good engineering calls for the head and the nut to be as small as is consistent with strength and utility in manipulation, to permit the placing of the bolt in the best position, that is, in the closest proximity to flanges and in corners. Very often the removal to a greater distance from the edge will necessitate the use of a larger bolt. All these matters were considered by the committee of the Institute, and confirm the writer in his preference for the standard of the Franklin Institute, as all bolts can be reduced in size of head without prejudicing their position, while enlargement involves practical difficulties without any good result. We have now two standards, and, that there are many who know how to work to either, is shown by the fact that all makers of bolts and nuts furnish what they are required to do under one or the other name, even if they do only publish as standard that adopted by the Government Board.

COLEMAN SELLERS,
Professor Mechanics, Franklin Institute.

PHILADELPHIA, November 14, 1884.

Book Notices.

THE CAR-BUILDERS' DICTIONARY: an Illustrated Vocabulary of Terms which designate American Railroad Cars, their Parts and Attachments. Compiled for the Master Car-Builders' Association, by Matthias N. Forney, Mech. Eng., assisted by Leander Garey, Superintendent of the Car Department, N. Y. C. and H. R. RR., and Calvin A. Smith, Secretary Master Car-Builders' Association (3d thousand). New York: Published by the Railroad Gazette, No. 73 Broadway, 1881.

This publication is a very valuable contribution to information of practical men, and is of a class much needed; its scope of usefulness is really much greater than its title would imply; the illustrations are far more complete and exact than are usually to be found in technical lexicons, proportions and dimensions of parts being indicated in most of its illustrations as fully as in most large cyclopedias and with a degree of exactness indicating much conscientious painstaking, the devices are those in actual practice and use rather than the contrivances which expand the records of the Patent Office. In the present state of railway practice and the necessity for cheapening charges for transportation, everything that contributes to the facility of making cars interchangeably useful on all railways is of great inportance, and to facilitate this result, the effort of this book is to secure exact and uniform understanding of terms employed throughout the country. This is not only in the proper direction, but is as well carried out as the nature of its subject-matter will permit. The modest apology for the appearance of advertisements in the work was hardly necessary, they are so well indexed that they really contribute valuable information to those in the craft, and whilst not perhaps just to the taste of many library readers, their presence in the work will, if we mistake not, be considered desirable and important by those practically engaged in railway operations and the manufacture of railway supplies.

Books of this scope and character are undoubtedly a great need of these times, and this appears to be both happily conceived and well executed.

Few books afford as much exactly stated information in so concise and easily accessible form, and the endorsement of the Master Car-Builders' Association makes it an authority for the craft. S. L. W.

CORRESPONDENCE.

EARLY COMPOUND ENGINES, AN ITEM OF HISTORY.

Committee on Publication of the Journal of the Franklin Institute:

GENTLEMEN:—In an article on the trial of the Steamer "City of Fall River," in the July number of the JOURNAL, allusion is made to early compound engines in this country, by note, as follows: "The first compound engines are, however, said to have been built by an engineer of a still earlier generation, Mr. I. P. Allaire." As early as 1830 or 1832 there were on the Hudson River two steamboats with compound engines, the

Swiftsure and *Commerce*. Their engines were of the upright square form, or cross-head pattern (very few of that form now in use and none built). The high-pressure cylinder being forward and the low-pressure being abaft the paddle-wheel shaft, and both connected to it by cog-wheel gearing. About the same time the *Post Boy*, with similar machinery, built by Mr. Allaire, was sent to New Orleans. In the machinery of the above steamers the exhaust steam of the high-pressure cylinder passed directly to the low-pressure cylinder without the intervention of valves or receiver between the two cylinders. The *Swiftsure* and *Commerce* were in use for several years, and the machinery of the former subsequently taken out and replaced by the ordinary beam engine. The compound engine, built by the late Erastus Smith was of the ordinary beam pattern, except that it had two steam cylinders, the high-pressure being *within* the low-pressure one. Their diameters were thirty-seven and eighty inches, and stroke of piston eleven feet. This form has not been duplicated. The present compound engine has practically but little resemblance to those that preceded it, and is very much more economical. B. H. B.

PHILADELPHIA, October, 1884.

Franklin Institute.

[*Proceedings of the Stated Meeting, held Wednesday, November* 19, 1884.]

HALL OF THE INSTITUTE, November 19, 1884.

The President, Mr. William P. Tatham, in the Chair.

Present, 115 members, and 20 visitors.

The Actuary presented the following resolution, passed at the stated meeting of the Board of Managers, held Wednesday, November 12th, viz.:

Resolved, That the Board of Managers recommend to the Institute the necessity ; in view of the rapidly increasing value and extent of its library, the absence of proper accommodations for the same, and for other branches of the Institute's work, that active efforts be at once commenced to obtain subscriptions for the erection of a more commodious and fire-proof building.

Seventy-four (74) persons were elected to membership in the Institute since the last meeting.

The Secretary, by direction of the Committee on Science and the Arts, reported that the Committee had recommended the award of the "John Scott Legacy Premium and Medal" to G. Morgan Eldridge, of Philadelphia, for his "Improvement in Electro-Magnetic Protectors for Electrical Instruments," that the recommendation had been advertised for three months, as prescribed in the regulations, and that no objection thereto had been received.

On motion of Mr. H. R. Heyl, seconded by Mr. Hector Orr, it was

Resolved, That the recommendation of the Committee on Science and

the Arts to award the "John Scott Legacy Premium and Medal" to G. Morgan Eldridge, of Philadelphia, for his improvements in "Electro-Magnetic Protectors for Electrical Instruments" be approved; and that the Secretary be directed to notify the "Committee on Minor Trusts of the Board of City Trusts," of the action of the Institute.

Mr. Coleman Sellers presented a report on the "Tercentenary of the University of Edinburgh," to which he was appointed to represent the Institute. Mr. Sellers also made, by request, some comparative "Remarks and Comments on the Condition of the Mechanic Arts Abroad and at Home, and on Technical Education."

On Mr. Orr's motion, seconded by Mr. Washington Jones, the meeting passed a vote of thanks to the speaker for his interesting and instructive discourse.

Mr. Seller's remarks have been referred to the Committee on Publication.

The Secretary's report embraced a detailed description of the experiment of purifying the water pumped into certain of the reservoirs in the city of Philadelphia, by aeration, on the large scale. These experiments were conducted by Col. William Ludlow, Chief of the Water Department, at the suggestion of Professor Albert R. Leeds, Chemist to the Department.

The proposed amendment to Article III, Section I, of the By-Laws, offered by Mr. J. D. Rice at the October meeting, and postponed to the present meeting, was called up for consideration as deferred business. Mr. Rice advocated his proposition at length, when, on motion of Mr. Coleman Sellers, seconded by Mr. G. Morgan Eldridge, the subject was laid on the table.

The consideration of the resolution previously reported from the Board of Managers then came up, and, on Mr. Coleman Sellers' motion, seconded by Dr. Ziegler, it was

Resolved, That it is the sense of this meeting that a committee be appointed to secure subscriptions to a fund for a new building.

The President appointed to serve on this committee, Messrs. Charles H. Banes (Chairman), Chas. Bullock, Fred'k Graff, Wm. D. Marks and Coleman Sellers.

Mr. Eldridge advocated the holding of an exhibition as the best means of accomplishing the object contemplated in the above resolution. He therefore offered the following:

Resolved, That it is the sense of the Franklin Institute that an exhibition shall be held in the Exhibition Building, in West Philadelphia, during the autumn of 1885, and that the Board of Managers be requested presently to instruct the Committee on Exhibitions to take the steps necessary for the holding of the said exhibition.

The resolution was seconded by Mr. Coleman Sellers, and, after some discussion as to the propriety of devoting the contemplated enterprise to a Health Exhibition, upon the general plan of those held in Berlin, and, more recently, in London, was carried unanimously.

Adjourned.

WILLIAM H. WAHL, *Secretary.*